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NATIONAL ASSESSMENT OF THE URBAN PARTICULATE PROBLEM

Volume X - Seattle

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Volume X - Seattle

June 1976

Gordon L. Deane, Frank Record, Project Director

GCA Technology Division
Burlington Road
Bedford, MA 01730

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This document is one volume of a sixteen-volume report presenting an overall assessment of the particulate problem, which was conducted by GCA/Technology Division for EPA.

This particular document is one of fourteen single-area volumes that provide working summaries of data gathered in the fourteen urban areas studied. These city reports critically provide documentation and background information for Volume I of the study - National Assessment of the Particulate Problem - Final Report. Volume I should be considered the primary output of the report.

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NATIONAL ASSESSMENT OF THE URBAN PARTICULATE PROBLEM

Volume X
Seattle, Washington

FINAL REPORT

by
Gordon L. Deane
Frank Record, Project Director

CCA/Technology Division
Burlington Road
Bedford, Massachusetts 01730

Contract No. 68-02-1376, Task Order No. 18

EPA Project Officer: Thompson G. Pace

Prepared for

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

June 1976

This final report was furnished to the Environmental Protection Agency by the GCA/Technology Division in fulfillment of the requirements under Contract No. 68-02-1376, Task Order No. 18. The contents of this report are reproduced herein as received from the contractor. The opinions, findings and conclusions are those of the authors and not necessarily those of the Environmental Protection Agency.

FOREWORD

This document is part of a 16-volume report assessing the urban particulate problem, which was conducted by GCA/Technology Division for EPA.

This particular document is one of the 14 single city volumes that provide working summaries of data gathered in the 14 urban areas during 1974 to support an assessment of the general nature and extent of the TSP problem nationwide. No attempt was made to perform detailed or extensive analyses in each urban area. Rather, the city reports are intended as a collection of pertinent data which collectively form a profile of each urban area. This, in turn contributes to a comparative analysis of data among the 14 areas in an attempt to identify general patterns and factors relating to attainment of the TSP problem nationwide. Such an analysis has been made in Volume I of the study-National Assessment of the Urban Particulate Problem-National Assessment. The reader is referred to this volume as the summary document where the data is collectively analyzed.

This and the other 13 city reports are viewed primarily as working documents; thus, no effort was made to incorporate all the reviewer's comments into the text of the report. The comments were, however, considered during the preparation of Volume I and are included herein in order to alert the reader to different points of view. The 16 volumes comprising the overall study are as follows:

Volume	I = National Assessment of the Urban Particulate Problem
Volume	II = Particle Characterization
Volume	III = Denver
Volume	IV = Birmingham
Volume	V = Baltimore
Volume	VI = Philadelphia
Volume	VII = Chattanooga
Volume	VIII = Oklahoma City
Volume	IX = Seattle
Volume	XI = Cincinnati
Volume	XII = Cleveland
Volume	XIII = San Francisco
Volume	XIV = Miami
Volume	XV = St. Louis
Volume	XVI = Providence

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GCA/Technology Division wishes to sincerely thank those persons and organizations who made significant contributions to this effort. Ongoing project supervision was provided by Thompson G. Pace of EPA's Control Programs Development Division. The case study in Seattle was greatly assisted by the cooperation and helpfulness of the staff of the Puget Sound Air Pollution Control Agency, particularly Milton Svoboda, Ray Saito, Ron Bixby, and Barry Wallace. In addition, much guidance and information was obtained from Michael Schultz and George Hofer of EPA Region X.

EXECUTIVE SUMMARY

The report summarized herein presents the analyses of the particulate situation in the Seattle area conducted as part of the study for the national assessment of the problem of attainment or nonattainment of the National Ambient Air Quality Standards for particulates. Seattle represents a moderately industrialized area, with above-average heating requirements and a definite rainy season, that has had some success in reducing emissions and particulate concentrations though not enough to attain the standards. Fugitive dust generated in the industrial valley during the dry season has been implicated as a major contributing source to the ambient levels of particulates in Seattle.

In addition to a discussion of this fugitive dust problem, analyses of the air quality levels, emissions, regulations, monitoring network, and meteorology, are included in this report. The major findings in each of these areas are summarized below in the order in which they appear in the text.

AIR QUALITY

The trends in TSP levels at several monitors have been primarily down during the past 8 years though an upturn has been noted in the past 2 years. Of those stations reporting a full year of data, the national primary annual air quality standard for particulates (75 $\mu g/m^3$) was exceeded at two stations in the industrial area of Seattle and the secondary annual standard (60 $\mu g/m^3$) was exceeded at another two sites -- one in the industrial valley and one in the city. The highest annual geometric mean

was 105 $\mu g/m^3$ at a site in the industrial valley which is being considered for relocation back away from the road. Violations of the 24-hour standards occurred five times for the primary and 31 times for the secondary standard out of a total of almost 700 observations in 1976.

The spatial distribution of the TSP concentrations is related to the topographical characteristics of the region. The highest concentrations (60 to 105 $\mu g/m^3$) are centered in the industrial valley with the levels lower in the city (53 to 63 $\mu g/m^3$) and lowest in the residential areas east of the valley (35 $\mu g/m^3$).

EMISSIONS

The spatial distribution of emissions in the area varies widely from almost no major sources in the eastern part of the county to the densely industrialized Duwamish Valley. Local estimates of the impact of fugitive dust in the valley amount to almost a third of the major point sources in the area. Consistent data on yearly emission levels is not available to establish any correlation between TSP concentration and emissions. However, utilizing best available data, an estimate of 50 percent for the degree of reduction since 1969 was made. This estimated reduction was in agreement with that expected by EPA over a comparable period of time yet it was not paralleled by a similar improvement in air quality.

REGULATIONS AND SURVEILLANCE

The sources in the Seattle area are controlled by regulations from both the state's Department of Ecology (DOE) and the Puget Sound Air Pollution Control Agency (PSAPCA). The PSAPCA regulations are generally as stringent or more stringent than the DOE's regulations; however, the DOE has promulgated regulations for several types of industry. Surveillance of the sources is performed through the use of the permit system, visible emissions, and complaints. The majority of sources are determined to be in

compliance through theoretical calculations though some stack testing is done to determine compliance, especially with new construction.

NETWORK DESIGN

The network reviewed was found to be generally well-designed in terms of neighborhood selection and monitor siting. Monitors are spaced at intervals of about 1 mile from the mouth of the Duwamish Valley, where industrial emissions are concentrated, to the agricultural and residential areas to the south. This network is backed up by modeling and monitoring for wind speed and direction at numerous sites to better understand the wind flow in the complex topography.

The primary difficulty noted was that the monitors in the center city area (Public Safety Building, Food Circus) were located two to three times higher than the other monitors which were uniformly located at the more standard 15 to 25 feet above ground level. This increase in height is expected to result in lower readings and may therefore downplay the importance of planning in this area. In addition, there have been some relocations of monitors in the Duwamish Valley that have recorded high levels of TSP. While the movements of these monitors are probably appropriate, it was felt that some guidelines for documentation of these moves would be helpful.

METEOROLOGY AND CLIMATOLOGY

Numerous meteorological parameters were investigated for Seattle including the yearly and monthly variations in precipitation and space heating demands, the average wind speed and number of days of precipitation each month, and other ventilation characteristics of the region such as mixing height, inversions, and the movement of air masses through the region. While the seasonal pattern in space heating and various ventilation parameters (mixing height, inversion frequency) would tend to indicate higher

levels of particulates in the winter, the significant pattern of precipitation, with a definite rainy winter season and dry summer-fall, has an overwhelming influence on the seasonal pattern of TSP levels. On an areawide basis, the TSP concentration is 50 percent higher during the dry months than during the rainy season.

Precipitation has apparently also had an impact on the yearly levels of particulates. From 1969 to 1973 the improvement in air quality has been paralleled by increasing levels of precipitation. In 1973 and 1974, however, when the yearly precipitation decreased 25 percent, the TSP concentration increased. This trend was noticeable throughout Region 5 at rural, background sites. At these sites, the TSP levels noted a 5 $\mu g/m^3$ increase to 35 $\mu g/m^3$.

URBAN ACTIVITY

Insufficient data was available for an analysis of the possible impact on TSP levels due to the paving and conditioning of roads in the Duwamish Valley. Data from a DOE study underway to compare the effect of the location of a monitor with respect to a heavily traveled road was reviewed. Forty sets of paired measurements taken over the period from October 1974 to June 1975 indicated that the monitor located approximately 15 feet back from the road had values averaging over 60 percent higher than the concentration at the monitor located approximately 100 yards back from the road. Further analyses of this data have not indicated other expected relationships so it is undergoing additional study.

CONCLUSIONS

The results of this study indicated that significant reductions in the emissions from industry may be possible under a more stringent process weight rate regulation. However, the impact that such a regulation would have is not known at this stage due to insufficient information on the impact of the fugitive dust sources. In addition, the complexity of

the topography and meteorology of the area may call for other, less traditional control measures. The seasonal pattern of TSP may mean that controls for fugitive dust and/or seasonal controls on industry (fuel switching in the summer) would be most cost effective.

REVIEWERS' COMMENTS

The draft report for each city was submitted to interested EPA, state, and local officials for comment on the contents and findings. Comments of an editorial nature were reconciled; comments of a substantive nature which reflect differences of opinion were compiled and are presented below.

METEOROLOGY

1. It is strongly implied in the document that precipitation is a controlling influence on the TSP levels. While there is some cause and effect relationship in terms of scavenging and suppression of the fugitive dust, the importance of this mechanism may be overstated. It is noted in the report that the TSP levels in Seattle show good correlation with the seasonal variation in rainfall and even some correlation with the departure of rainfall amounts from normal. However, one needs to also consider that the rainfall pattern in Seattle is primarily controlled by the seasonal (and day-to-day) changes in the windflow patterns over the area. Late summer and early fall are characterized by a northerly flow pattern, light winds, a subsidence or marine inversion of the Los Angeles type, and either clear skies or diurnal stratus and fog. During the winter the southerly flow brings long periods of thick overcast, frequent precipitation, moderate winds, and a typically near pseudoadiabatic lapse rate.

OCA notes that from a meteorological point of view the seasonal TSP levels should follow an inverse relationship with wind speed and mixing depth. In the case of the Seattle TSP, they noted that the wind speed relationship seemed to hold but that TSP levels do not correlate well with seasonal mixing depth climatology such as given in AP-101. Thus they concluded that the precipitation scavenging mechanism and dust suppression were the dominate external controls on TSP levels. One needs to be careful here in that the way that mixing depths are handled for precipitation days in AP-101, Appendix B is arbitrary and, in the case of the Seattle climate, may be misleading. On precipitation days in Seattle, the observed lapse rate through the extensive cloud decks is typically pseudoadiabatic with few if any inversions. This may be a good indicator of neutral mixing conditions, in the pseudoadiabatic sense, through the depth of the clouds (up to 20,000 feet above sea level).

Meteorologists at the Washington Department of Ecology are of the opinion, from analysis of 3-hour CDH values, that most of the TSP loading in summer and fall frequently occurs in the early morning hours when a surface inversion is present. They also note that wintertime inversions, when they do occur, are most intense and are associated with very high TSP levels on individual days. Because the number of such days is limited the wintertime monthly mean TSP levels are low.

Therefore, the mixing depth/transport wind mechanisms cannot be discounted as the controlling external influence on Seattle TSP levels. The occurrence/nonoccurrence of precipitation may only be a good indicator of these ventilation characteristics.

2. Do not agree with the inference that precipitation has the main impact on particulate levels. Admittedly this correlates very well. Precipitation in this area is almost invariably accompanied by a change of air mass and improved ventilation. Therefore, the loaded air is moved out and dispersed coincidental with the rain. During the rainy season, pollutants can rarely "build up" because of the existing ventilation and unstable low level conditions. Scouring is slow and cannot produce the dramatic changes during a 24-hour sampling period.

PROCESS WEIGHT REGULATION

1. Disproportionate emphasis is placed on process weight regulation in Executive Summary (page xiii) and in main body (pages 31, 32, 33, and 52). The actual effect of changing the process weight regulation on emissions should be re-evaluated to determine if this is a meaningful step. Initially we had assumed that there would be an annual review (including computer modeling where appropriate) of control strategy where ambient standards were not being met.

2. The authors focus many of their comments on the process weight regulation with such comments as "Tightening of the process in eight regulation to the studywide average stringency would result in as much as 40 percent less emissions from major sources." (Page 52). Now this comment is not new. EPA made a similar comment in reviewing our first implementation plan; and the response now as then is: even if a more stringent process weight regulation were in effect for all large sources in the Duwamish area, their emission reduction (if any) would have a negligible effect on the ambient TSP.

3. In addition, this Agency includes the back half (impinger catch) of the Method 5 particulate sampling train, which is more stringent than the current EPA practice.

4. The process rate regulation (discussed on pages 31 and 52) is used in conjunction with the maximum allowable grain loading of 0.1 gr/scf

SECTION I

STATEMENT OF THE PROBLEM

CHARACTERISTICS OF THE REGION

The Puget Sound Intrastate Air Quality Control Region (AQCR) encompasses the Counties of King, Kitsap, Pierce and Snohomish (Figure 1). It covers an area of about 6,100 square miles, extending roughly 60 miles east and west by 100 miles north and south and straddling the central part of Puget Sound, a large irregular mass of salt water containing numerous islands. On the east side of the AQCR is the 3000 to 6000 foot high Cascade Range, which effectively blocks the ventilation of the Puget Sound Lowlands in that direction. On the west side, the Olympic Mountains intercept a large part of the western rain-bearing winds. However, the winds can sweep freely north and south through the valley.

More than half of the population of the State of Washington resides in the AQCR yet the heavily forested eastern section of Snohomish, King, and Pierce Counties is largely uninhabited. All of the region's cities and most of the population are located along a narrow 20-mile wide lowland corridor, mainly on the east side of the Sound. This leads to the high urbanization of the area: 93 percent, 82 percent, 72 percent and 44 percent urbanized for King, Pierce, Snohomish, and Kitsap Counties, respectively. The region has two Standard Metropolitan Statistical Areas (SMSA's). The largest, ranking 22nd in the nation, is the Seattle-Everett SMSA with a population of 1.4 million; the Tacoma SMSA is much smaller with only 405,000 inhabitants. Both of these areas have had declining populations in the past several years.

Figure 1. Puget Sound Intrastate Air Quality Control Region

The industry of the area is also located along this lowland area. The Puget Sound Region's economic structure is heavily oriented toward manufacturing and service activities in aerospace, shipbuilding, trade, transportation, and forest-related industries. While the Region's pollution problems are similar to those of many heavily-urbanized areas, sources especially noteworthy in the Seattle area include steel manufacturing, iron foundry, lumber mills, kraft pulp mills, two sulphite pulp mills, and various lumber, single and plywood mills. Figure 2 provides a graphical representation of the employment mix in the AQCR by 2-digit Standard Industrial Classification (SIC) code; this figure demonstrates the overwhelming influence of the transportation equipment industry on the employment in the area.

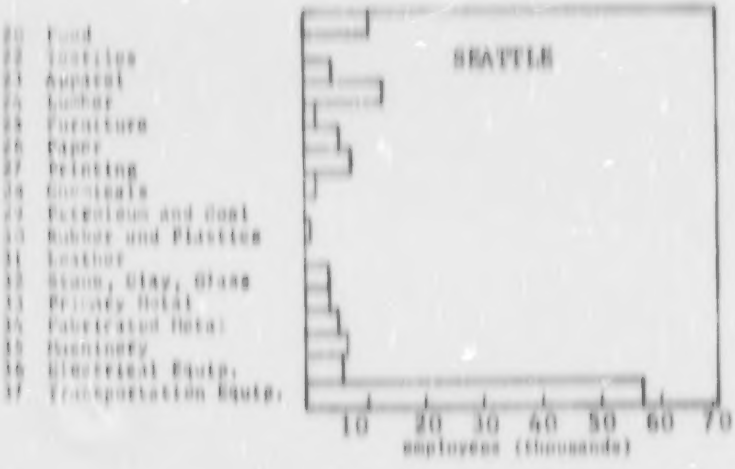

Figure 2. Manufacturing employment in the Puget Sound AQCR

The climate in the AQCR is predominately a mid-latitude, west coast, marine-type, with dry season and pleasant temperatures during the summer and rather mild but rainy winters. Precipitation averages less than 40 inches in the lowlands bordering Puget Sound, while 60 to 100 inches is common in the Cascade Mountains in the Region's eastern sector.

Some of the factors which influence the climate are: its location in the belt of the prevailing westerly winds, the distance and direction of the Pacific Ocean, the terrain, and the position and intensity of the semipermanent high and low pressure centers located over the north Pacific Ocean. The Cascade Mountains serve as an effective barrier in preventing the cold continental air in the winter and the warm air in the summer from reaching the Puget Sound lowlands. Most air masses reaching Puget Sound have their source regions over the Pacific Ocean; the maritime air has a moderating influence in both winter and summer. The prevailing wind is from the southwest in fall and winter, gradually shifting to northwest in late spring and summer.

Seattle has a relatively high number of expected episode days in a 5-year period with mixing heights less than 1000 meters and wind speeds less than 4 m/sec. Over this period, 10 different episodes lasting at least 2 days each may be expected to occur with the greatest number of episode-days in the autumn.[1] Table 1 presents mean ventilation characteristics for Seattle.

Table 1. VENTILATION CHARACTERISTICS FOR SEATTLE

	Annual		Winter		Spring		Summer		Autumn	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
Mean mixing height (m)	705	1175	824	718	838	1577	576	1419	585	987
Mean wind speed through mixing layer (m/sec)	5.2	5.4	6.2	5.4	5.9	6.2	4.2	4.9	5.0	5.0
Median $\overline{X}/Q$ for a 10-km city (sec/m)	10	10	10	10	10	10	11	10	11	10

AIR QUALITY PLANNING

The program of air pollution control in the State of Washington is a cooperative effort between the State agency, which is the Department of Ecology (DOE) and the various local agencies. The Washington Clean Air Act of 1967, as amended, places the primary responsibility for control of air pollution into the hands of local agencies. The first of the local agencies formed under this act was the Puget Sound Air Pollution Control Agency (PSAPCA). Prior to this, the City of Tacoma and the City of Seattle had separate programs. In July of 1967, King, Pierce, and Snohomish Counties formed a three-county agency with Kitsap County joining in January 1970.

The Puget Sound AQCR was designated a Priority I region for all pollutants except SO_2 for which it was considered IA (the designation for SO_2 has been changed to Priority III). The implementation plan to meet the National Ambient Air Quality Standards (NAAQS) was completed by the Puget Sound Agency, in cooperation with the Department of Ecology, and submitted to EPA in January 1972. The state implementation plan (SIP) predicted that, under the then existing state regulations and Regulation I of the Puget Sound Air Pollution Control Agency, the particulate standards would be attained by July 1975. The analyses was based on projected emission levels given plant capacities, new plants, and growth in the region and using these emissions in the Martin-Tikvart atmospheric diffusion model. The SIP is currently approved for all pollutants except oxidants in the Puget Sound AQCR. However, the standards for particulates are not expected to be attained and the Puget Sound area is designated as a maintenance area solely for particulates.

AIR QUALITY SUMMARY

There were 14 monitoring stations operating in the four-county region during all or part of 1974; five of these are being run by the Washington

State Department of Ecology. These stations are distributed around the region with one station in a rural region east of Seattle and the rest reasonably distributed among the industrial, commercial, and residential sectors. As shown in Figure 1, the greatest density of stations is in the Seattle metropolitan area. The location of the stations and the types of monitors operated at each are given in Table 2. Of the 10 stations with hi-volume air samplers operating in 1974, 23 of them operated every month.

Two Seattle area stations have been monitoring particulate matter since February 1965, thereby accumulating 10 years of data. These samplers have operated on an intermittent schedule sampling continuously for 24 hours every third day from February 1965 through December 1968, every fourth day from January 1969 through December 1972, and every sixth day since January 1973. A total of 20 stations have acquired at least 4 years of data through the end of 1974.

An analysis technique which allows a reasonable determination of trends is the moving mean or average. As applied to suspended particulates, a 12-month moving geometric mean relates directly to the annual standard. This moving mean is calculated by computing the 12-month geometric mean for consecutive 12-month intervals and identifying each resultant value with the ending month for the particular 12-month interval. These values may be easily plotted on a graph to depict observed concentrations which relate directly to the annual standard. A variation of this technique of portraying a trend which requires more years of data is the calculation of the moving geometric mean in multiples of 12 months. For example, 24- and 36-month moving geometric means smooth out some of the year to year variations in meteorology and short-term changes in source emissions to more clearly depict the trend.

Data has been acquired continuously at the Public Safety Building (KC01) in downtown Seattle since February 1965, and the 12-, 24- and 36-month

Figure 3. Location of monitoring sites in the Puget Sound AQCR[7]

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Table 1. PUGET SOUND AIR POLLUTION CONTROL AGENCY ATMOSPHERIC SAMPLING NETWORK 1974

"M" Data summary by Washington State Dept. of Ecology

TYPE OF SAMPLE:

1. High-volume Sampler
2. Sulfur Dioxide (SO_2)
3. Bubbler Nodes (CO_2)
4. Hivol Spec. & Chem.
5. Nitrogen Dioxide (NO_2)
6. Fluoride
7. Hydrocarbon
8. Dust

moving geometric means are plotted in Figure 4. The 12-month moving geometric mean plot shows short-term fluctuations, but also depicts a long-term downward trend which appears to level out at about the value of the annual standard. This long-term trend is even more evident in the 24- and 36-month moving geometric mean graphs.

The other Seattle area station with about 10 years of data is located at 2700 West Commodore Way in a commercial area. The 12-month moving geometric mean plot (Figure 5) indicates a long-term downward trend with values generally below the annual standard except for an upturn during 1973. In February 1974, a reversal of the short-term uptrend occurred and is sustained for the remainder of the year. The 24- and 36-month moving geometric mean graphs more clearly depict the long-term downward trend which appears to level off during the past 3 years.

Parallel to depicting levels of suspended particulates in the urban areas, it is important to document these concentrations in the nonurban regions. The Agency has operated a single station near the Tolt Water Reservoir in the foothills of the Cascade Mountains since November, 1966. The 12-, 24-, and 36-month moving geometric mean graphs (Figure 6) all depict a reasonably constant value of about 14 micrograms per cubic meter which is neither increasing nor decreasing. Evidently this station is not significantly affected by the urbanized areas in the Puget Sound region, and this value is considered to be an average background value for the air of the Puget Sound region.

In 1974, the majority of the AQCR was meeting both the primary and secondary annual standards. Of those stations reporting a full year of data, the national primary annual air quality standard for particulates (75 $\mu g/m^3$) was exceeded at two stations in the industrial area of Seattle and the secondary annual standard (60 $\mu g/m^3$) was also being exceeded at two other stations in Seattle and one in Tacoma. Figure 7 provides an isopleth map of the 1974 annual geometric means in the AQCR indicating the horizontal distribution of suspended particulates throughout the region. The

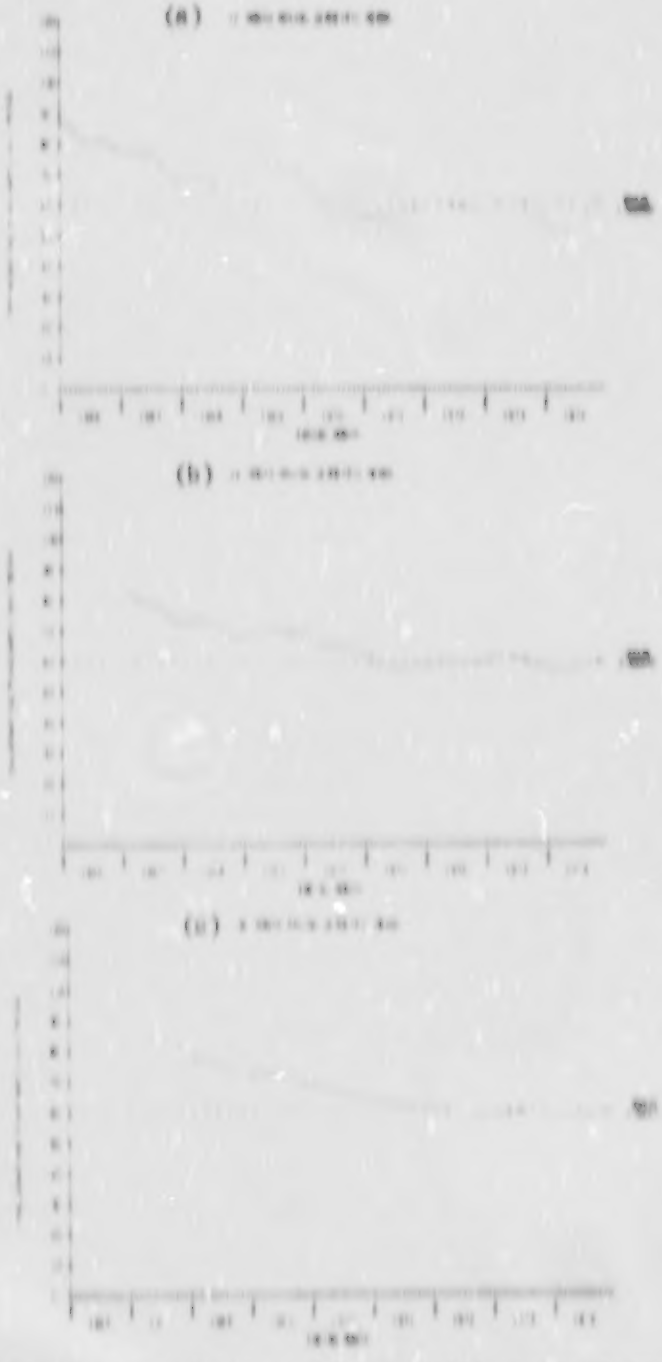

Figure 4. Trends in total suspended particulates at the Public Safety Building, Seattle[2]

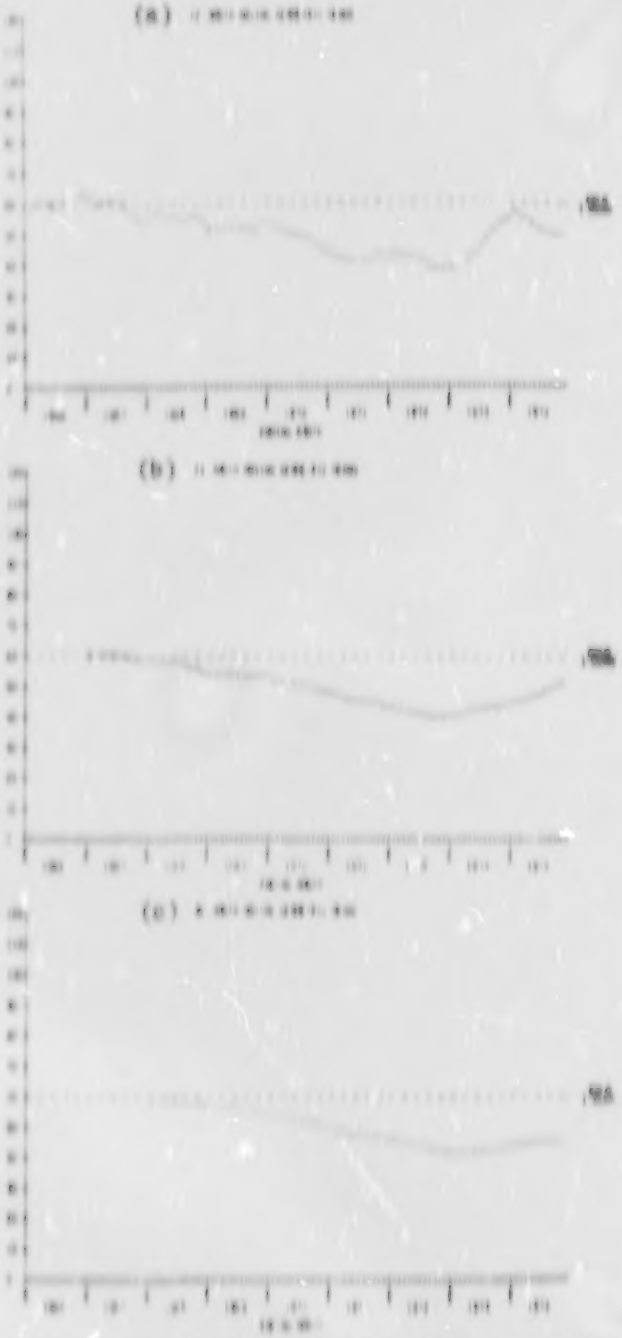

Figure 5. Trend in total suspended particulates at the USDA Station in Seattle[2]

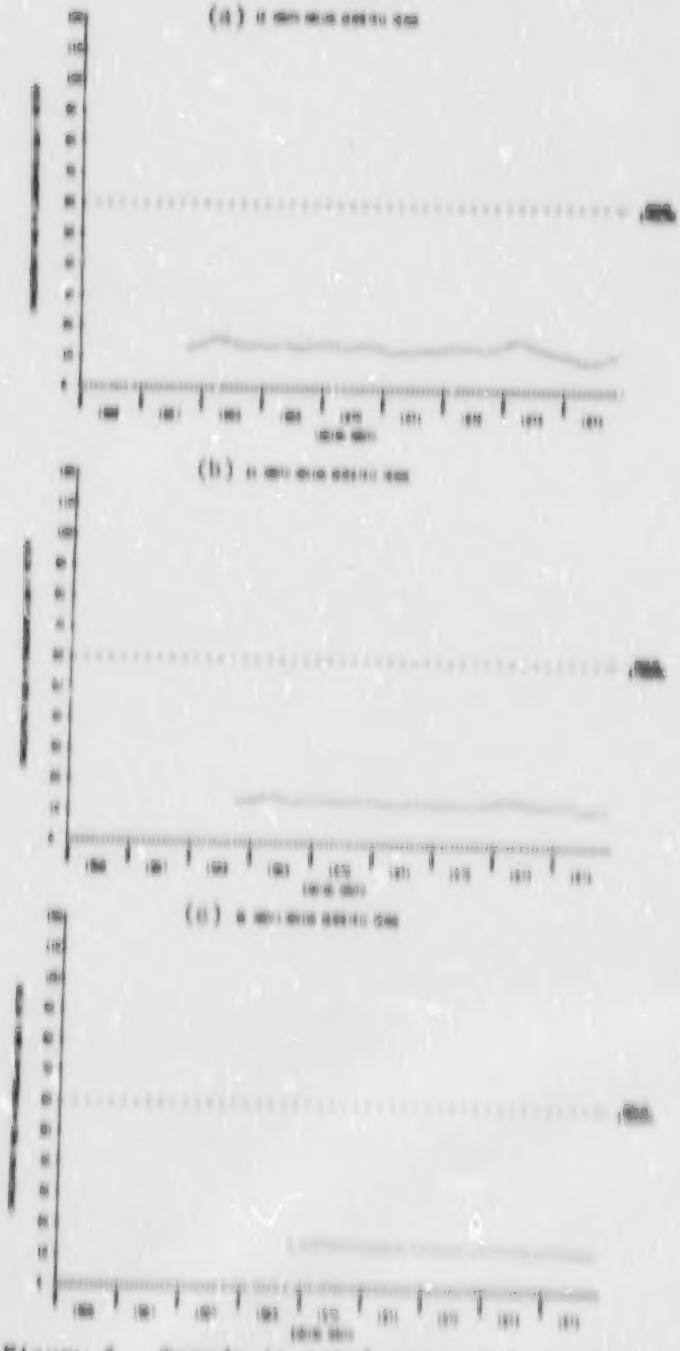

Figure 6. Trends in total suspended particulates at Tolt River Watershed, King County

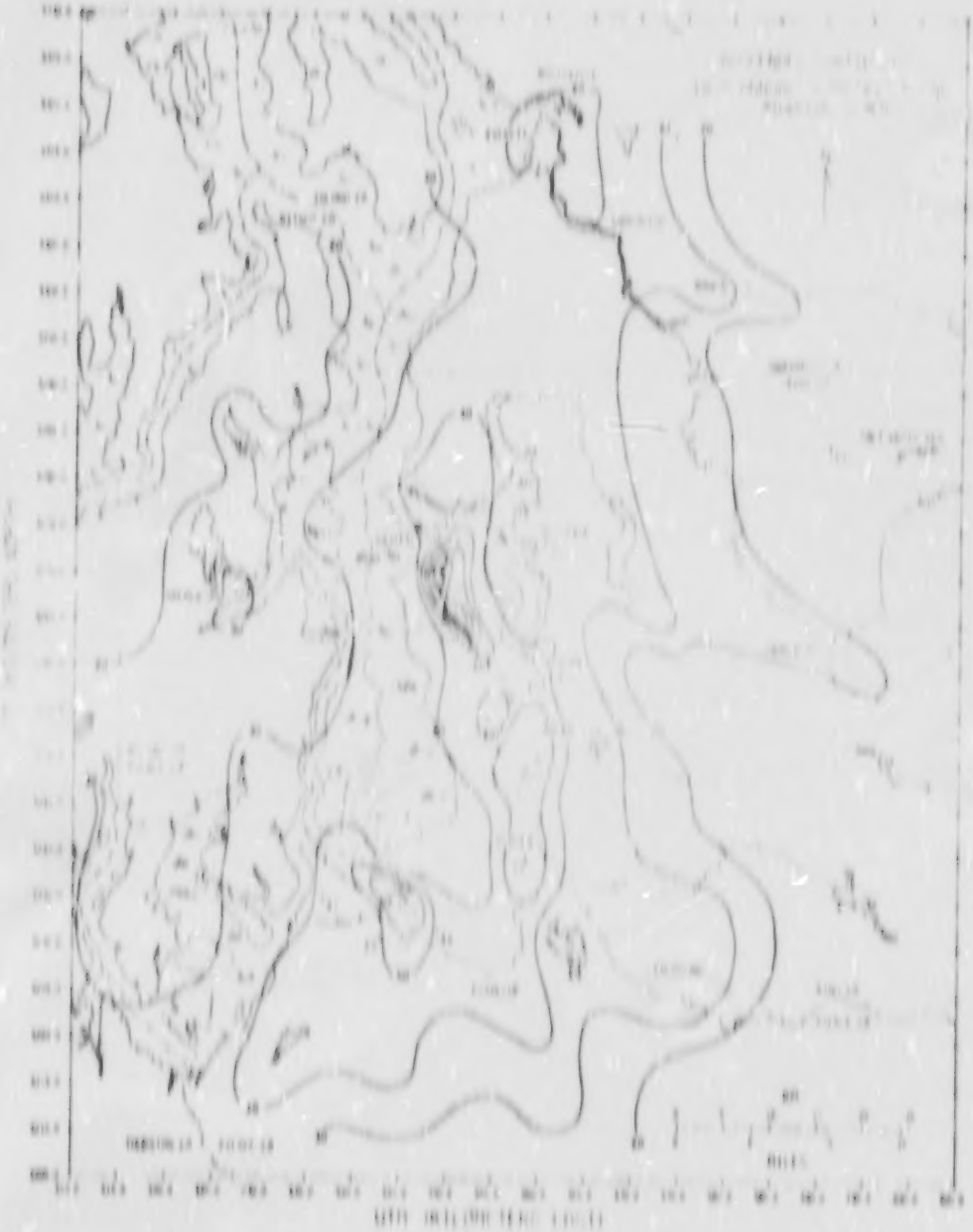

Figure 7. TSP annual geometric means at monitors and isopleths in the Puget Sound AQCR, 1974 ($\mu g/m^3$)

development of these annual average isopleth maps by the PSAPCA required the input of (1) measured air quality data, (2) meteorological conditions, (3) topographic influences, (4) demography of the area, and (5) the particulate emissions of all sources. This map indicates the problem of attainment of the annual standards is a matter of local influences as opposed to a regionwide problem.

Of the 1580 individual 24-hour samples taken in 1974, 67 (4.2 percent) of the samples violated the secondary 24-hour standard (150 $\mu g/m^3$). One station operated by the PSAPCA violated the primary 24-hour standard (260 $\mu g/m^3$) once in 1974 and another station operated by the DOE in the same industrial area - the Duwamish valley in Seattle - is reported to have violated the primary standard four times in 1974. This DOE site, which also had the highest annual mean, is under study regarding its siting and will be discussed further under monitor siting in Section II of this report. Another DOE station in Tacoma is known to have violated the primary 24-hour standard at least once.

Table 3 summarizes the 1974 monitoring history of the monitoring stations in the AQCR, arranged by county and type of neighborhood in which the monitor is located. More detailed data on the stations visited in the course of the study are given in Section II.

Table 1. HISTORY OF TSP MONITORING SITES IN THE PUGET SOUND AQCR - 1974

Location	Area class	Geo. mean	Std. geo. dev.	Max.	Date	Number of observations: Intermittent parameter standard	Intermittent picket standard	Total
Salt River Watershed	RUR	13	2.50	58	Jul 23			97
Tulalip Test Facility[a]	RUR	18	2.11	153	Oct 8			15
Everett & Pine, Everett[b,b]	RES	41	2.05	121	Jan 5			10
Medical-Dental Bldg., Everett	COM	48	1.61	110	Oct 8			61
U.S.C.G. Station, Seattle	COM	50	1.65	159	Jan 11	2		61
Good Circus Bldg., Seattle Center	COM	45	1.51	97	Dec 26			59
Public Safety Bldg., Seattle	COM	61	1.66	189	Oct 8	1		62
Harbor Island, Seattle	IND	77	1.76	257	Sep 20	0		65
6513 8th Ave. N. Hwy. Var 0., Seattle	IND	68	1.76	265	Jan 5	0	1	65
6700 E. Fwy. Var 0., Seattle[c]	IND	109	1.97	329	Jan 5	10	5	58
South Park, Seattle[d]	RES	50	1.87	153	Oct 14			56
10000 M. Hwy. Var 0., Seattle[e]	IND	80	2.17	235	Oct 8	1		31
Duwamish Valley, King Co.	RES	18	1.82	157	Jan 5			61
Puget Power Bldg., Bellevue	COM	32	1.57	78	Jan 11			61
S.E. Dist. Health Center, Renton	SUB	33	1.82	93	Dec 21			60
Municipal Bldg., Renton	COM	53	1.81	119	Jan 11			61
Southcenter, Tukwila[f]	COM	36	1.56	81	Dec 31			11
Duwamish Dist., King Co.	RES	35	1.71	132	Aug 9			59
1235 N. Pearrel Ave., Kent[g]	COM	53	2.04	234	Sep 15	3		33
Main St. & Auburn Ave., Auburn	COM	51	1.67	138	Jan 5			61
Sumner Jr. H.S., Tacoma	RES	38	1.76	117	Jan 8			61
Main Arterial Elec., Tacoma	IND	60	1.78	211	Aug 9	5		61
Fife St. H.S., Fife	COM	43	2.05	167	Jan 8			61
Cascadia College, Tacoma[h]	RES	56	2.10	218	Jan 11	11	6	53
Willard Elem. School, Tacoma	RES	49	2.0	171	Oct 8	5		61
Hess Bldg., Tacoma	COM	62	1.92	185	Oct 9	2		60
112th St. Bus. & Tech Lab, Lakewood[i,i]	RES	38	2.00	121	Oct 8			32
N. 26th & Pearl, Tacoma	COM	61	2.15	111	Jan 11			60
City Hall, Bremerton	COM	31	1.57	66	Oct 17			53
Navy Jr. H.S., Bremerton	RES	35	1.68	97	Oct 15			60
All station totals						67	61	1,560

[a]Washington State Department of Ecology Stations.

[b]Site established 10/08/74

[b]Site discontinued 5/31/75

[c]Site established 3/10/75

[d]Site established 7/13/74

[e]Site established 11/07/74

[f]Site established 6/02/74

[g]Site established 5/30/75

[h]Data not available

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SECTION II

ANALYSES

This section presents the individual analyses that were performed on the data gathered for the study of the particulate problem in Seattle. It attempts to correlate various factors which are known to influence air quality with the measured ambient TSP concentrations. These factors include those that most often come under the jurisdiction of the air pollution control agency - emissions, regulations, and monitor siting - and other factors that are not usually or cannot be controlled - urban activity, meteorology, etc.

EMISSIONS

The Puget Sound Intrastate AQCR is a moderately industrialized area with most of the sources compacted into several localities. Data in the current National Emissions Data System (NEDS) for the area indicates that industrial processes contribute the largest share (44 percent) of the total inventoried particulate emissions and 67 percent of the total point source emissions. Inventoried area source emissions are approximately half the magnitude of particulate emissions from point sources.

In King County, the primary area for study under this effort, the industrial processes account for 77 percent of the point source emissions and 29 percent of the total inventoried particulate emissions. However, inventoried area sources contribute almost 70 percent more than point sources to the total particulate emissions in King County. Emissions from transportation sources represent 63 percent of these area source particulate emissions (see Table 4).

Table 4. [illegible] EMISSIONS FOR THE PUGET SOUND AQCR AND KING COUNTY (In tons per year)

	Puget Sound AQCR			King County			County percent of AQCR
	Point	Area	Total	Point	Area	Total	
Fuel combustion	(9,318)	(3,843)	(13,161)	(1,122)	(2,149)	(3,271)	(25)
Electrical	9,318	3,843	13,161	1,122	2,099	3,221	25
Residential	–	1,728	1,728	–	1,111	1,111	64
Electrical	23	–	23	23	–	23	100
Industrial	7,244	938	8,174	1,013	448	1,461	17
C-I	2,048	976	3,024	98	538	637	21
Industrial process	(23,814)	–	(23,814)	(1,742)	–	(1,742)	(7)
Chemical	31	–	31	31	–	31	97
Coal/Petroleum/Wood	1,274	–	1,274	858	–	858	67
Metals	4,882	–	4,882	–	–	–	0
Mineral	5,845	–	5,845	2,894	–	2,894	50
Petroleum	7,977	–	7,977	–	–	–	0
Solid waste disposal	(438)	(647)	(1,085)	(38)	(288)	(326)	(30)
Commercial	98	–	98	8	–	8	8
Residential	–	371	371	–	134	134	48
C-I	98	201	301	–	89	89	43
Industrial	336	176	512	30	72	42	35
Transportation	–	(5,033)	(5,033)	–	(5,187)	(5,187)	(37)
Gasoline	–	8,443	8,443	–	3,832	3,832	45
Diesel	–	1,833	1,833	–	812	812	50
Aircraft	–	339	5539	–	208	208	39
Vessels	–	423	423	–	235	235	56
Miscellaneous	–	1,471	1,471	–	719	719	36
Total	29,588	15,294	44,882	4,922	8,261	13,183	29
Percent of combined	65.9	34.1	100	37.3	62.7	100	

The spatial distribution of emissions in the AQCR is quite varied. Almost all sources lie in the valley along the Sound, the various inlets, and rivers in the area. Figure 8 locates the point sources in King County and provides an idea of the relative size of each source. As may be seen from this figure, the greatest density of point sources is along a river south of Seattle, an area known as the Duwamish Valley. Figure 9 identifies, by the dashed line, that area defined as the Duwamish Valley by PSAPCA and also provides a closer look at the location of sources in the Duwamish Valley area.

The wide variation in the degree of industrialization of the AQCR makes analysis of the emission levels difficult for levels reported at the AQCR or county level. A particular example of this is reflected in the emissions from fuel combustion. Table 5 provides a breakdown of the emissions from combustion based on fuel usage for the AQCR and King County as reported in NEDS. This table indicates that almost 55 percent of the emissions from fuel combustion in the AQCR are from the burning of wood and in King County this contribution is over 30 percent. However, these emissions are almost totally due to combustion occurring in the rural areas of the AQCR and county and are not of significance when considering the violation of the standards in the metropolitan areas. In the Seattle-Everett SMSA in 1970, based on the U.S. Census of Housing, 44 percent of dwelling units used distillate oil and the other units were evenly divided between gas and electricity usage with only 0.2 percent using coal.

The above NEDS data does not include any estimate of the emissions from possible fugitive dust sources. A calculation of the preliminary data supplied from the MRI study[1] of dirt roads, dirt air strips, construction, and agricultural tilling indicates that the fugitive dust emissions from these sources would be more than 22 times the total tonnage as the inventoried emissions, and, in King County by itself, the fugitive dust is over 30 times the total inventoried emissions (see Table 6). Almost

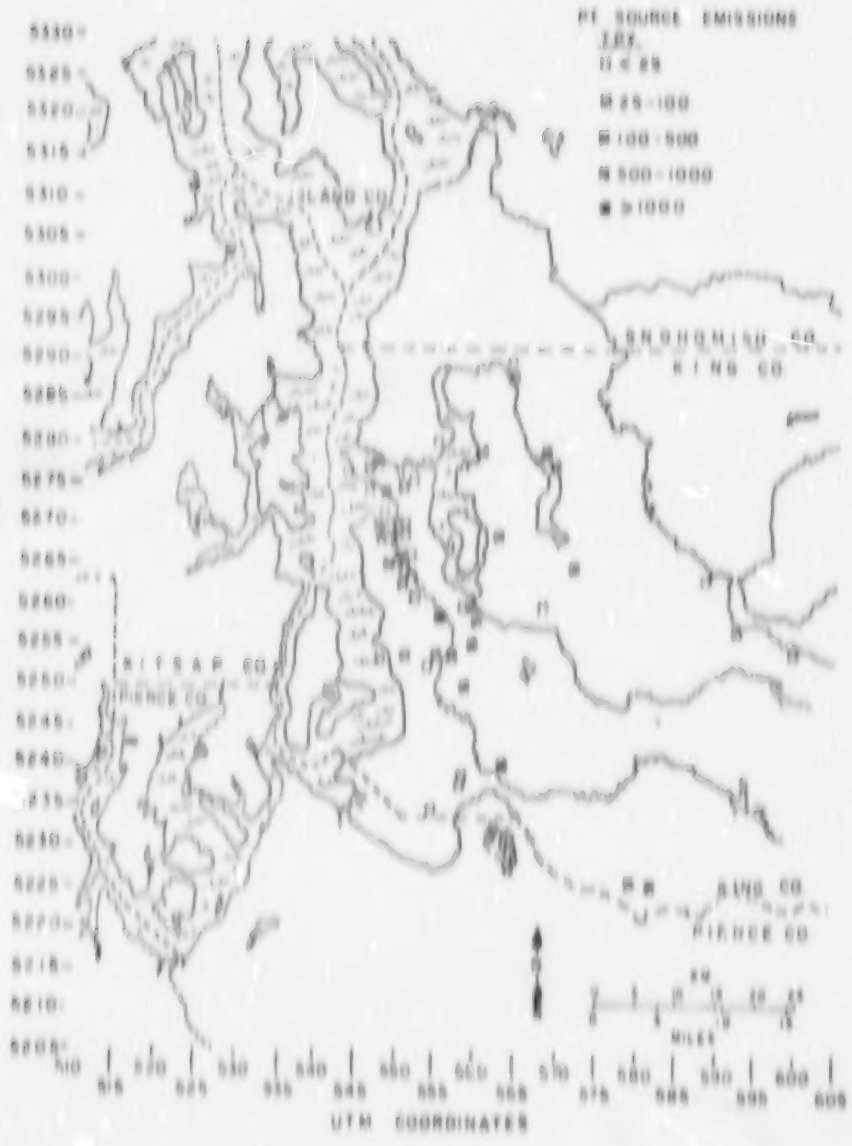


Figure 8. Location of point sources in King County

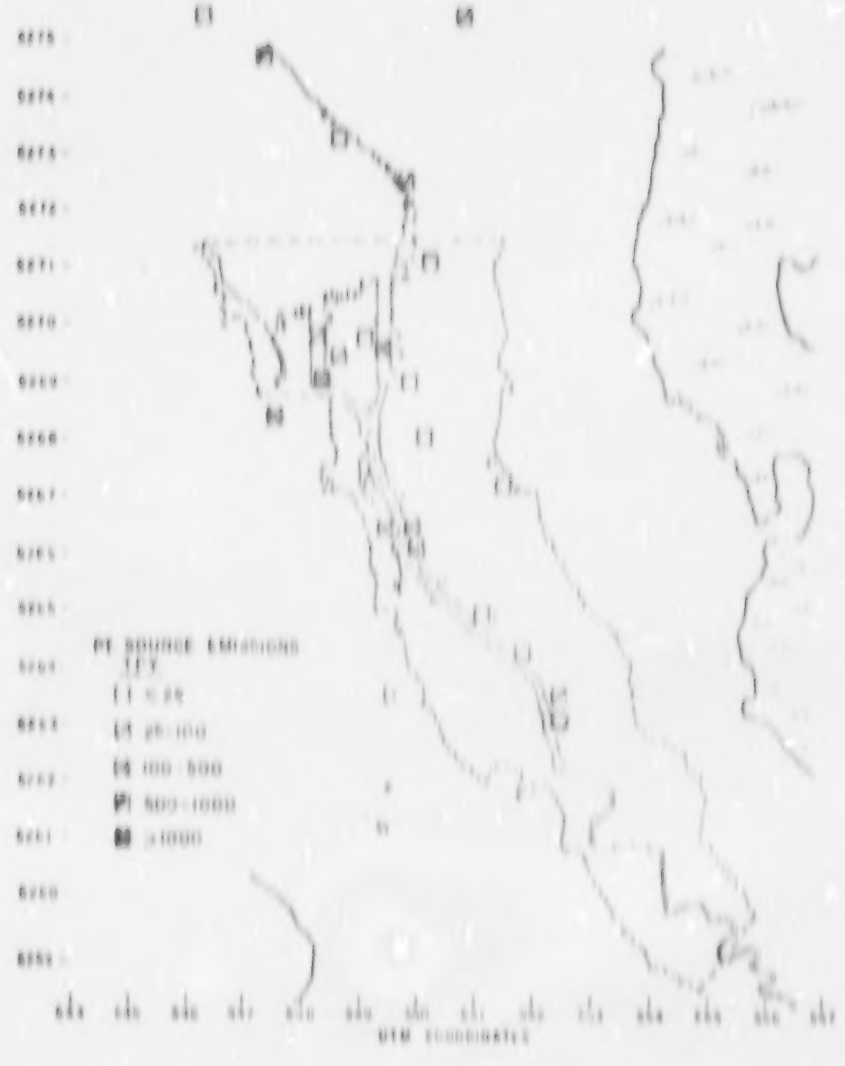


Figure 9. Location of point sources in the Bucomish Valley

Table 5. RATIO OF EMISSIONS FROM FUEL COMBUSTION BY FUEL TYPE TO TOTAL EMISSIONS DUE TO FUEL COMBUSTION, PUGET SOUND AQCR AND KING COUNTY[a]

Area	Source type	Fuel type					Total
		Bituminous coal	Residual oil	Distillate oil	Natural gas	Wood	
AQCR	Point	0.133	0.059	0.010	0.008	0.509	0.719
	Area	0.006	0.101	0.118	0.018	0.039	0.280
King County	Point	0	0.067	0.009	0.013	0.282	0.351
	Area	0.007	0.215	0.334	0.045	0.046	0.648

[a]From NEDS data

Table 6. FUGITIVE DUST EMISSIONS IN THE PUGET SOUND AQCR (in tons per year)[a]

County	Unpaved roads	Dirt air strips	Construction	Land tilling	Total	Percent of AQCR
King (0980)	196,765	44	204,680	39	401,528	40
Kitsap (1020)	110,625	40	13,072	20	123,757	12
Pierce (1560)	160,480	16	70,348	59	230,903	23
Snohomish (2000)	171,100	35	66,068	106	237,289	24
Total	638,970	135	354,168	224	993,477	100
Percent of total	64	< 1	36	< 1	100	

[a]From an MRI Study[1]

all of these emissions are contributed from unpaved roads (66 percent) and construction activity (26 percent).

The problem of fugitive dust in Seattle has been recognized and analysed in several studies by J. W. Roberts. In a thesis prepared by Roberts in 1971[3], he developed an emission inventory for fugitive dust generated as a result of vehicular activity in the Duwamish Valley. In this study, Roberts attempted to identify not only those total emissions that may be expected to result from traffic on dusty paved roads and gravel roads but also the amount that would remain suspended for any period of time. Particulates less than 10 microns in diameter were defined as the suspended portion and, on average, this amounted to approximately 23 percent of the total emissions.

Table 7 details the emission inventory calculated by Roberts for the Duwamish Valley air basin with the grid numbers referring to the map in Figure 10 as given in his thesis. This table indicates that there is an estimated emission level of 2560 tons of particulates per year within this area due to traffic on paved gravel roads and that 655 tons of this would remain suspended. While the determination of this level may have some problems due to sampling directly behind a moving vehicle and it can be expected to vary greatly depending upon climatic and individual road conditions, the amount of "suspended" particulates generated is significant. It amounts to almost one-third of the emissions from the major point sources in the area and is emitted directly into the breathing zone without much dilution as occurs with emissions from stacks.

Due in part to this research and the recognition that these sources are contributing to the ambient air levels (and water pollution) in the area, some stabilization of roads (about 15 miles in 1974) and paving of parking lots has occurred in the Duwamish Valley. Unfortunately, this is a relatively recent and ongoing activity so that sufficient data is not available to establish an estimate of the impact on air quality that these programs are having.

Table 7. POLLUTION INVENTORY FOR DUSTY PAVED ROADS AND UNPAVED ROADS IN THE DEVANESH VALLEY[a]

Grid	Dusty paved roads, emissions in t/y			Gravel roads, emissions in t/y			Total emissions, t/y	
	Miles road	Total particulate	Suspended particulate (< 10 μ)	Miles road	Total particulate	Suspended particulate (< 10 μ)	Total particulate	Suspended particulate (< 10 μ)
11/16 B	4.8	36	5	1.2	74	21	110	26
11/16 C	9.4	57	11	4.4	176	48	229	59
11/17 B	11.9	68	14	1.8	218	60	286	74
12/16 A	14.6	83	17	0.1	4	1	87	18
12/16 B	11.9	68	14	4.7	425	114	493	128
12/16 C	18.2	25	21	0.6	67	18	173	39
12/16 D	11.0	62	13	1.3	101	28	163	41
12/17 A	7.8	44	9	2.4	224	61	268	70
12/17 B	4.3	24	5	2.2	644	174	668	180
13/16 A	6.4	48	10	0.2	16	4	64	14
Totals	108.4	574	119	18.3	1,961	534	2,540	655

Figure 10. Duwamish Air Basin gravel road location

While no consistent set of data was available to establish any long-term trends in emissions from different source categories, annual emission inventories for King County for the years 1969 to 1972 had been compiled by the PSAPCA. (However, differences in emission factors and approaches to compiling the inventories have varied over this time and no attempt has been made to update previous inventories.) In addition, the EPA Region X office had compiled a 1973 inventory for a study of the King County area[3] and the NEDS data is supposedly representative of 1974 emissions. Therefore, utilizing these data bases, it is possible to develop an approximation of the trends in emissions over time.

Figure 11 provides a graph of the changes in these emission inventories for the major source categories and the total emissions (divided by two to fit on the graph). Emissions of approximately 1050 tons/year from dirt roads, included in the 1973 inventory, were excluded in the 1974 total to try to maintain consistency between the inventories. Despite the differences in the emission inventories, the magnitude of reduction of emissions is almost equivalent to the 40 percent reduction expected in the Region X report.[3] The major problem in establishing a trend is for the transportation category, however all other sources show a noticeable continuing downtrend. An average of annual TSP concentrations at three stations (USCG, Public Safety Building, Food Circus) is also plotted on this figure. This air quality plot indicates that, while improvements in air quality were noted in the early years, 1973 and 1974 have shown increasing levels at a time when emissions have continued to decrease. Possible factors relating to this discrepancy are investigated under the discussion of meteorology and climatology.

LEGAL AUTHORITY, REGULATIONS, AND SURVEILLANCE

The program of air pollution in control in the State of Washington is a cooperative effort between the state agency, which is the Department of Ecology (DOE) and the various local agencies. The Washington Clean Air

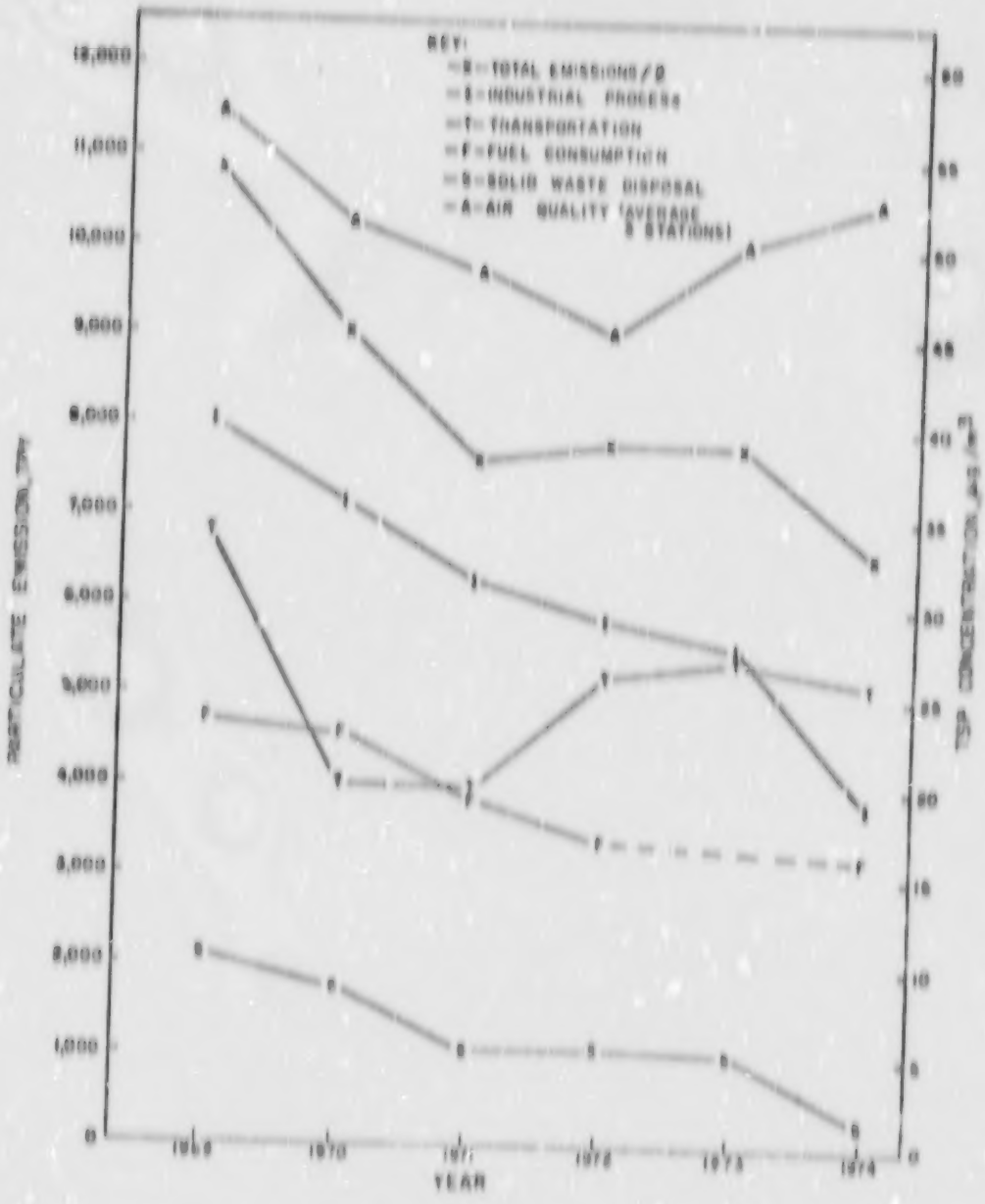


Figure 11. Particulate emission and TSP air quality trends in King County

Act of 1967 as amended in 1969 and 1970 and 1971 places the primary responsibility for control of air pollution into the hands of local agencies. The first of the local agencies formed under this act was the Puget Sound Air Pollution Control Agency (PSAPCA). Prior to this, the City of Tacoma and the City of Seattle had separate programs. In July of 1967, King, Pierce, and Snohomish Counties formed a three-county agency with Kitsap County joining in January 1970.

Regulations

The Department of Ecology is organized to provide technical advice and consultation for the local agencies and to assist them in their programs and planning. The state agency has also been granted the authority to set standards and assume jurisdiction for certain source categories if it is determined that these should be controlled on a uniform statewide basis. The State of Washington's air pollution regulations are applicable statewide unless the local regulation is more stringent, in which case the local regulation would be applied. Some areas under the direct jurisdiction of the state agency can be designated sensitive areas by the director, depending on present and predicted ambient air quality, population density, topographic and meteorological conditions and other factors. These areas would be subject to more stringent regulations.

The state's regulations include sections on compliance schedules, source registration, odors, fugitive dust, sulfur dioxide, hazardous substances, combustion and general process sources, as well as separate sections on the following sources: wigwam burners, asphalt batching, hog fuel boilers, orchard heaters, grain elevators and catalytic cracking units. There are separate regulations for primary aluminum plants, open burning, field burning, sulfite pulping, Kraft pulping, thermal power plants, chemical wood pulp mills, and suspended particulates.

The regulations which DOE has adopted for the ambient air quality standard is identical to the secondary National Ambient Air Quality Standards (NAAQS) for particulates with one exception of interest. Included in the standard is the possibility of variance from the standard in areas east of the Cascade Mountain Crest "in recognition of natural dust loading:"

> (1) If concentrations, measured at approved background locations, exceed 30 micrograms per cubic meter of air on individual sample days, the concentration of suspended particulate matter measured at any primary air mass station shall not exceed 150 micrograms per cubic meter of air plus background as a maximum 24-hour concentration not to be exceeded more than once per year.
>
> (2) If concentrations, measured at approved background locations, exceed 20 micrograms per cubic meter of air as an annual geometric mean, the concentration of suspended particulate matter at any primary air mass station shall not exceed 40 micrograms per cubic meter of air, plus background, as an annual geometric mean.

The ambient air quality standards for particulates that were promulgated by the PNAPCA under Regulation I are identical to those of the DOE; and, since the region is west of the Cascade Mountains, it has no exempted areas. However, an additional standard for particulate has been adopted which regulates the level of fallout based upon the area which is being measured:

> (1) Ten grams per square meter per month (10 $g/m^2/mo$) in an industrial area; or
>
> (2) Five grams per square meter per month (5 $g/m^2/mo$) in an industrial area if visual observations show a presence of wood waste and the volatile fraction of the sample exceeds 70 percent.
>
> (3) Five grams per square meter per month (5 $g/m^2/mo$) in residential and commercial areas; or
>
> (4) Three and one-half grams per square meter per month (3.5 $g/m^2/mo$) in residential and commercial areas if visual observations show the presence of wood waste and the volatile fraction of the sample exceeds 70 percent.

Regulation I includes general policy and implementation sections as well as rules governing ambient air quality and required control measures. It

regulates the sulfur content of fuel, odors, and emissions of sulfur oxides, particulates, and oxides. The general regulation adopted by the agency contains provisions requiring the registration of sources and a notification of construction to be filed for any new construction. The agency has the authority to deny construction upon finding that the new facility will result in a violation of the standards adopted by the agency.

As the controls adopted by the PSAPCA are generally equivalent to or more stringent than those of the DOE, they are the ones summarized below.

Open Burning - Open burning is restricted, depending on location, purpose, air pollution potential and the material to be burned. Small fires on residential property are generally allowed, provided that the material to be burned is not prohibited material and depending on the proximity of other structures.

Visible Emissions - After July 1, 1975, visible emissions cannot be darker than No. 1 on the Ringelmann chart (20 percent opacity) for periods greater than 3 minutes in any 60 minutes.

Refuse Burning - After June 30, 1975, emissions from incinerators are limited to 0.10 grains per standard cubic foot of exhaust gas, adjusted to 12 percent carbon dioxide. Incinerators must be of the multi-chambered design.

Fuel Burning - Emissions from equipment existing before the effective date of the regulations are limited to 0.10 grains per standard cubic foot of exhaust gas adjusted to 12 percent carbon dioxide. For equipment installed after 10 October 1973 emissions are limited to 0.05 grains per standard cubic foot. The emissions from existing fuel burning equipment using wood residue cannot exceed 0.20 grains per standard cubic foot; the emission standard for new facilities is 0.10 grains per standard cubic foot.

Manufacturing Processes = The allowable particulate emissions for manufacturing processes are presented graphically in Figure 12 on a process weight rate basis. The further restriction that emissions not exceed 0.10 grains per standard cubic foot for existing installations and 0.05 grains per standard cubic foot for new facilities is also applied.

Fugitive Dust = Reasonable precaution must be taken to prevent particulate matter from becoming airborne.

The gist of the PSAPCA general process regulation in Figure 12 is superimposed on a graph which represents the maximum and minimum controls currently being applied in the U.S.[5] The dashed lines in this figure represent the most (least) stringent of the regulations in each size category and, as such, do not reflect the controls in any one jurisdiction. The shaded area in this figure reflects the arithmetic mean, plus and minus one standard deviation, of the 14 cities reviewed under this study. This figure indicates that the process weight rate regulation for the Puget Sound AQCR is much less stringent than may be reasonably expected. In fact, the PSAPCA regulation for particulate emissions for industrial processes was the least stringent of the process weight rate regulations in the 14 cities studied for a process weight rate greater than 4000 pounds per hour.

Similar reviews were conducted for regulations governing fuel burning, incinerators, and fugitive dust. The PSAPCA regulation was converted to a pounds per 10^6 Btu rate and plotted in Figure 13 on which a relative stringency measure had been graphed. The emission standards for fuel burning equipment are more stringent than the average for facilities with less than 400 million Btu per hour heat input and somewhat less stringent, relatively, for the larger size ranges.

The regulations for visible emissions and incinerators were found to be comparable with most other areas with incinerator controls being perhaps a bit more stringent than average for the smaller sizes (< 100 tons per day).

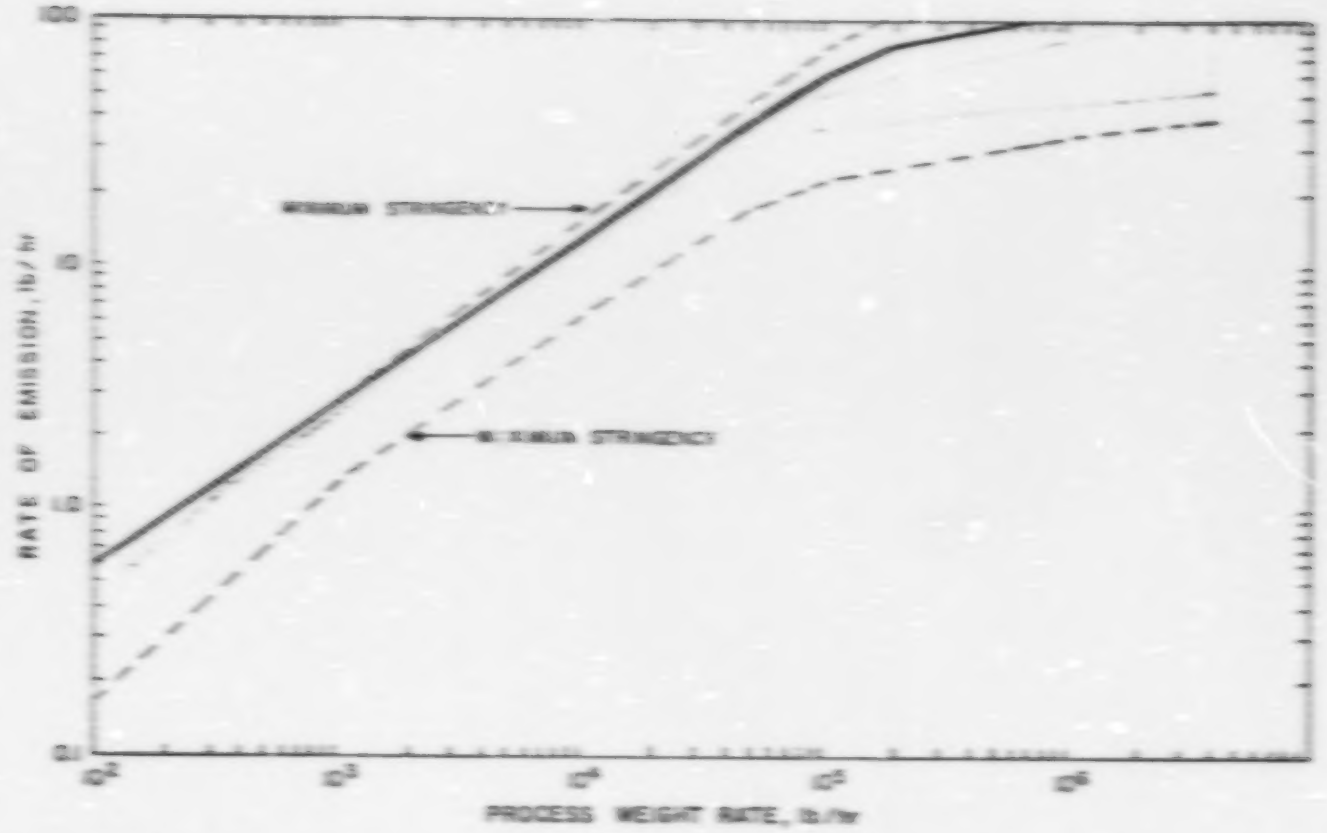


Figure 12. Comparison of stringency of the particulate emission regulation of PSAPCA with other controls nationwide – general processes

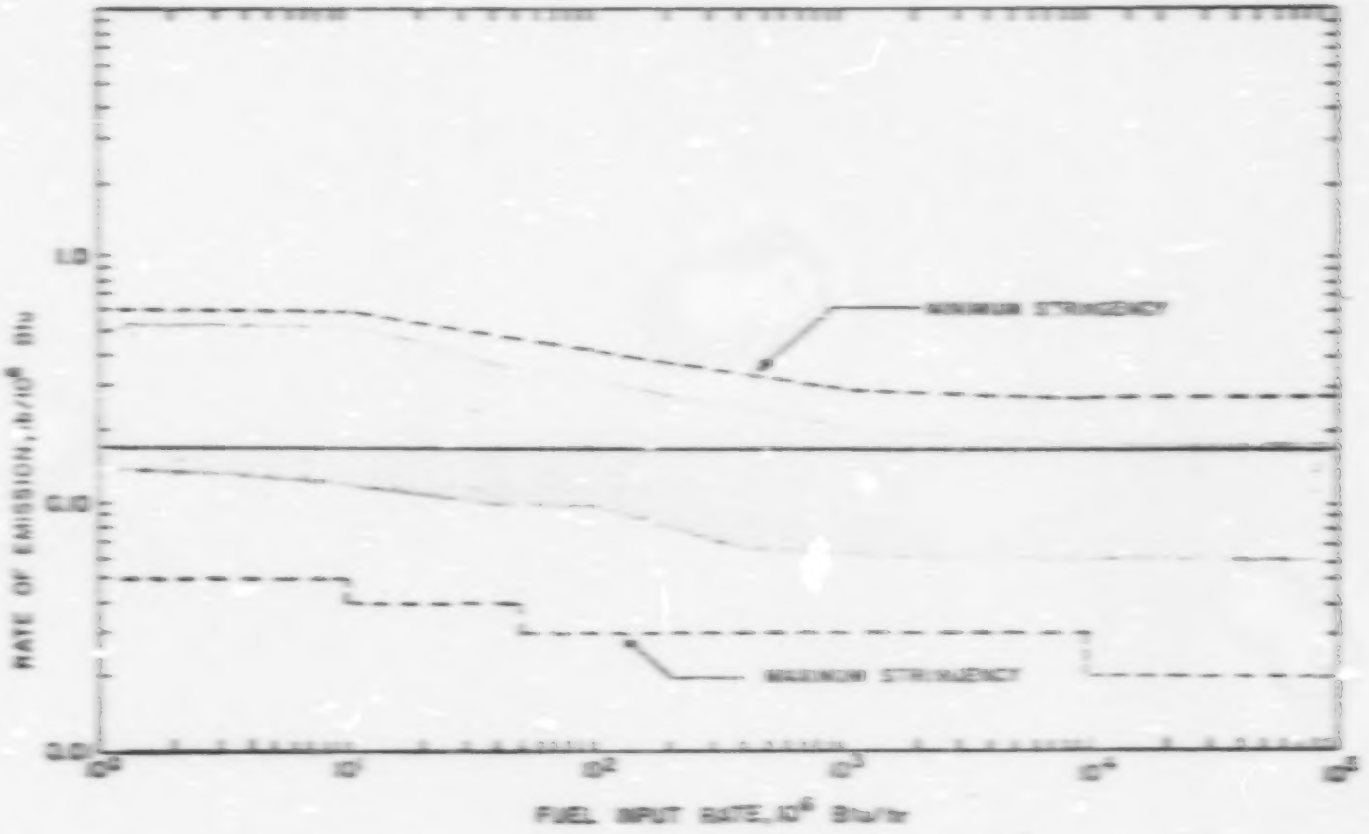


Figure II. Comparison of stringency of the particulate emission regulation of 7SAPCA with other controls nationwide - fuel burning

Surveillance Procedures

The surveillance of sources and enforcement of regulations in the Puget Sound AQCR are maintained by use of several techniques including inspection, registration of sources, notices of construction, and field surveys. The general program for enforcement by the PSAPCA is given below.[5]

Inspection

Field inspectors perform inspections on processes subject to regulation under Air Pollution Control regulations and standards. The types of inspections are:

1. Violation inspection
2. Follow-up and reinspection
3. Inventory inspection
4. Investigation of complaints
5. Miscellaneous inspections such as equipment breakdown, follow-up on variance conditions, compliance schedules, engineering final field reports, etc.

Complaints and inspection orders are relayed to field inspectors via two-way radio contact. The frequency of inspection depends upon the type. Complaints and visible emissions are investigated as soon as possible. Follow-up and reinspection on violations and variance conditions, status of compliance schedules, and inventory inspections are done on a scheduled basis. Each inspector conducts systematic coverage of his control area for optimum use of time.

Appropriate records of all types of inspections are made on appropriate forms and routed to source files. A file is initiated on the first contact with a source and maintained thereafter until retired for cause.

Violations

When evidence of a violation is established, a Notice of Violation is served in person by a field inspector or sent by certified mail, depending upon circumstances. The notice asks that the Agency be advised in writing within 10 days of the corrective action taken or to be taken to prevent continued or recurrent violations. If the source management fails to respond within the time specified, a second request for reply is

sent over the signature of the Supervising Inspector before resorting to one or more of the legal enforcement alternatives that are available. The most frequent legal action taken is issuance of a civil penalty.

Registration

Registration of active sources is accomplished on submission of one or more forms containing specific information regarding process equipment data, physical data, air pollution control equipment, combustion control devices, fuel used, fuel consumption and unit operation. Sources who do not respond when advised of the registration requirement are followed up in the field by air pollution inspectors.

Information obtained on the registration forms is entered onto load sheets for key-punching into computer cards, thereby creating a data bank from which emissions inventory, summaries, and other computer printouts can be generated at will.

Notices of Construction

Detailed plans and specifications submitted with Notices of Construction are reviewed by the Agency's engineers. Based upon plan evaluation the Agency will issue either an order or approval of an order to prevent construction. Failure to submit a Notice of Construction is a violation of Regulation I. In addition to the assurance that new sources will meet emission standards, a Notice of Construction system provides continuing help for the updating of source registration and emission inventory. Detailed information for this purpose is required to fulfill the Notice of Construction requirement.

Compliance Schedules

Compliance schedules are initiated by supervising inspectors on the recommendation of field inspectors. The air pollution source is supplied with a compliance schedule form and requested to submit the form by a fixed date. If the form is not submitted to the Agency on time and sufficient reason has not been presented, the supervising inspector recommends enforcement action.

On return of the compliance schedule form to the Agency, the supervising inspector forwards it to the Chief of Enforcement with recommendations. The Chief of Enforcement in turn forwards a copy of the schedule for Engineering review. On determining the proposed control methods are adequate for compliance and the completion dates are reasonable, the source is notified by letter that the compliance schedule is accepted, and that the Agency will not initiate legal action against the violator as long as the terms of the compliance schedule are met.

Variances

Applications for variances are made on forms supplied by the Agency and are accompanied by supporting data as required by the Board. Public notice of all hearings are placed in a newspaper officially designated by the Board and in a daily newspaper in the county from which the application is made. The Engineering Division studies the merits of the application and prepares a draft of staff recommendations to the Board. After hearing the applicant, the staff recommendations, and any other pertinent testimony, the Board directs its legal counsel to prepare a resolution containing the findings and decisions of the Board, for signature by the Chairman. This written notice of disposition is served to the applicant and made part of the record.

A review of the PSAPCA enforcement program indicated that it was quite an active program which apparently maintains complete and up-to-date files on most sources in the area. There are four inspectors in King County who visit each plant at least once per year to update the emission inventory. Yearly to thrice yearly source tests are conducted each year to check compliance, often after construction of a new source. Within the last couple of years most major sources have come into compliance.

NETWORK DESIGN

Because of the widespread nature of the ABCE and the multitude of neighborhoods that could be involved, no analysis of the monitoring network (Figure 1) for the whole ABCE was attempted. Instead, attention was directed at the monitoring network operated by the PSAPCA in and around Seattle. The network reviewed was found to be fairly well designed in terms of neighborhood selection and monitor siting with the assumptions noted below.

From the standpoint of emissions, topography, and associated local meteorology, the area of maximum concern is the Duwamish valley. This has been confirmed both by monitoring and by modeling and the monitoring effort has accordingly been concentrated along the valley. Monitors are spaced at intervals of about 1 mile from the mouth of the valley where industrial

emissions are concentrated to the agricultural and residential areas to the south. It is felt that this area has an appropriate density of monitors.

The monitoring sites reviewed in the course of this study are grouped in Table 8 according to the predominant characteristic of the neighborhood of each. This table also provides the height of each monitor, its slant distance from the nearest major road, the geometric mean for each station, and summarizes the siting comments for each monitor.

The primary difficulty noted was that the monitors in the center city area (Public Safety Bldg., Food Circus) were located much higher above ground that the other monitors visited. This increased height has been shown to produce lower readings than would be measured if the monitors were located at the more standard 15 to 25 feet above ground level. While the stations were not inappropriately high according to guidelines, lower sites would have been more in line with the other monitors in the network.

In addition to the sites listed in Table 8, the location of a previous monitor that had been discontinued was reviewed. This site was also in the Duwamish valley at a fire station in the 3200 block of 4th Avenue and was recording the highest concentrations of any monitor in the period 1958 to 1970. In the preparation of the SIP, this site was deemed inappropriate because its values did not fit with the modeling results. The site visit did not indicate any major sources that may have been impacting on the monitor to cause the higher readings.

A similar situation is currently being studied at the DOE site on E. Marginal Way. This site recorded the highest TSP value (103 $\mu g/m^3$) in the Puget Sound AQCR and is being considered for relocation because of its high values which appear to result from its proximity to the heavily traveled road. The DOE is operating another monitor 100 yards back from the road for comparison purposes; to date, its values have averaged almost 40 percent lower than the site closer to the road.

Table 8. CHARACTERISTICS OF SEATTLE MONITOR SITES REVISED

Neighborhood	EPA/PSD No.	Location	1974 annual geometric mean, $\mu g/m^3$	Height above ground, ft	Plant distance, ft	Siting comments
Residential	11	Mathildan Heights	45	15	30	Exposure good, only source would be residential home heating and traffic, on top of hill away from Duwamish Valley
	429	Dearborn Fire Station	48	25	300	Exposure good, located in Duwamish Valley down from steamer, almost rural surroundings
Commercial – Center City	42	Public Service Building	61	60	85	Seven stories vice to the SSW at monitor, 4 lost passage 12 feet from monitor, heavy traffic in area
	427	Fred Elmore	45	70	120	On hill above city and Duwamish Valley, in park, shows high readings only during inversions
Industrial	425	Duwamish Valley, 4500 block E. Marginal	69	20	25	Ideally located to industrial area, not source specific but probable influence from E. Marginal Way to west of monitor
	860	Harbor Island	77	15	75	Well located in center of major industrial area, lumber mill to north, shipyards to east, cement plant to south, steel to SW
	859	Duwamish Valley 30E site	105	15	25	Possible interference from low steam 5 feet above monitor to west, heavy traffic volume to west

Such movements of monitors which measure high levels of particulates raise some questions about the siting of monitors and the interpretation of the resulting citywide trends. While for most purposes monitors should not be located in areas heavily influenced by a single source, the relocation of those monitors recording high values may provide a picture of the TSP situation much less serious than actually exists. Though the moves may be totally appropriate, guidelines for a documentation of these siting decisions should be available.

METEOROLOGY AND CLIMATOLOGY

The general meteorology of the area appears to be one of the factors prominent in determining the TSP levels in Seattle. Numerous meteorological parameters were investigated for Seattle including the yearly and monthly variations in precipitation and space heating demands (degree days), the average wind speed and number of days of precipitation each month, and other ventilation characteristics of the region such as mixing height, inversions, and the movement of air masses through the region. Those factors which are known to be most influential for air quality levels - ventilation and precipitation - were found to be the same ones with the greatest seasonal variation. However, the analyses conducted indicated that the influence that precipitation has on the yearly and monthly TSP patterns in Seattle far outweighed any of the other meteorological factors. Therefore, the discussion below focuses primarily on precipitation and its impact after a short review of some of the other factors. Supporting data on the meteorological parameters are presented graphically in the appendix.

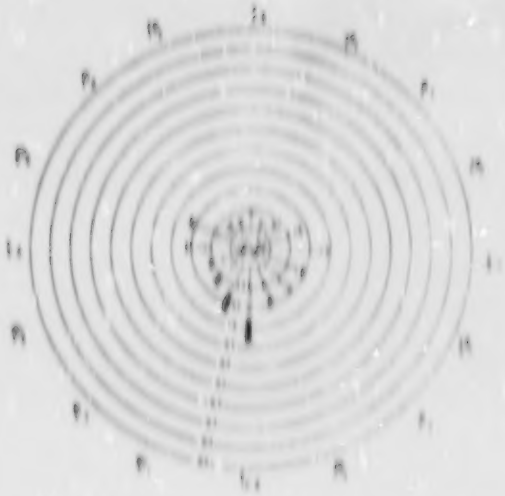
ventilation Characteristics

The topography of the region signficanntly affects the climatology and meteorology, having its major effect on the ventilation. The middle-latitude west coast climate of the Seattle-Tacoma area is modified by the imposing barrier of the Cascade Range on the east and to a lesser

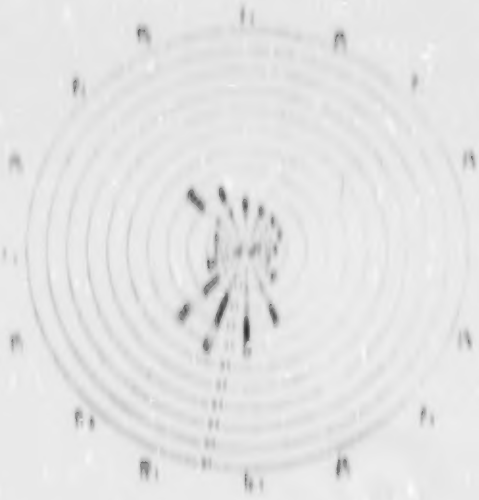
extent by the comparatively short Olympic Range in the west and northwest. The Cascades are very effective in excluding continental influences from the Seattle-Tacoma area, particularly in keeping cold air from draining westward during the winter. Occasionally the pressure distribution will result in a southward flow of cold air from Canada west of the Cascades and it is only under these conditions that extremely cold weather strikes the southern Puget Sound area. Since the southern end of the Puget Sound trough is open to the southwest winds generated by storms moving in off the ocean, the prevalent wind for the storm season of the winter and spring months is southwest. The trough of the Puget Sound is also open to the north allowing for strong winds from the northerly quarter during occasionally severe winter storms. During the summer months, the relatively light winds are influenced by the land- and sea-breeze effects as well as the channeling of the topography.

The wide variations in wind speed and direction that occur at different sites in the area can best be seen by looking at some of the wind roses at several sites operated by the PSAPCA. Wind roses at three sites around Seattle are given in Figure 14. In these roses, representing 1974 winds, each spoke points in the direction from which the wind blows. The length of each segment of a spoke indicates the relative frequency of winds of different speeds. Using the scale located to the lower right of the figure, these lengths may be converted to percentages of the total observations. The percentage frequency of winds from any given direction (without regard to speed) is expressed numerically beneath that direction on the perimeter of the roses. The percentage frequency of light and variable winds (winds less than 1.5 knots) is shown in the center of the rose.

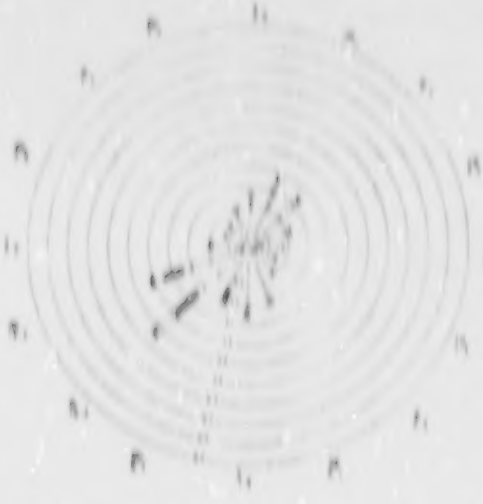
These roses indicate that, within 20 kilometers, one may expect to find significantly different wind patterns. Of particular interest is the high percentage of light and variable wind conditions. Such conditions are often associated with poor mixing and resulting high levels of particulates. For example, on many summer days light north winds pass over Elliot Bay



(a) NWS Urban Site, Station No. 8100



(b) Duwamish Valley, 4300 Blk, E.Marg. Way, Station No. 55



(c) McMicken Heights, Station No. 71

Figure 14. Wind roses at three sites around Seattle

into the Duwamish Valley and the air cooled by the water causes warmer air to rise. In such a manner a thermal lid is placed on the dispersion of air pollution. This condition compounds the effect of normal nighttime radiation inversions that occur during the same period of the year. The winds at the mouth of the Valley near Harbor Island are influenced by air currents from the Sound and this fact makes the Valley difficult to model.

For any given wind speed, the greater the mixing height, the greater the volume of air available to dilute the pollutants and therefore to lower their concentrations. The maximum vertical depth of the atmosphere available in any day for the mixing of polluted air usually occurs in the afternoon following the period of maximum surface heating and is known as the maximum mixing height. The minimum mixing height is associated with minimum surface temperatures and usually occurs at or around sunrise. From the data that was given in Table 1, it is apparent that this pattern of higher afternoon mixing heights is not followed in Seattle during the winter months. Instead, the afternoon mixing height is almost 13 percent lower than that calculated for the morning. In addition, the percentage of frequency of low-level inversions is higher in the winter and fall than during other seasons and the persistence of these inversions is also much greater (see Table 9).

While both of these conditions (inversions and mixing heights) would tend toward increased concentrations of particulates in the winter, such a trend is not seen due to the fact that the majority of precipitation also occurs during this time.

Table 9. PERCENTAGE OF FREQUENCY OF LOW-LEVEL INVERSION[a] (SEATTLE-TACOMA INTERNATIONAL AIRPORT)

Season	4 p.m.	7 p.m.	4 a.m.	7 a.m.
Fall	9	19	69	32
Winter	24	13	63	31
Spring	0	6	56	10
Summer	1	3	37	19

[a]Hosler, Charles R., 1961: Low-level inversion frequency in the Contiguous United States. Monthly Weather Review, vol. 89, Sept., 1961, 319-339

Precipitation

Precipitation is normally considered to be the meteorological parameter which has the maximum impact on air quality levels, aside from ventilation rate. It helps to clean the air of particulates through washout and rainout and can suppress the rise of pollution levels by wetting down particulates that would be resuspended if dry or even washing particulates off the streets into sewer systems if the rain is heavy enough. The expected relationship is one of inverse correlation with the pollutant concentration. Seattle has a well defined seasonal pattern of precipitation with as much as eight times the precipitation in the winter months than in the summer months on a normal basis. In 1974, this trend was even more pronounced with only 0.01 inch of precipitation recorded in August and 7.78 inches in January.

Because of the expected inverse relationship between TSP concentration and precipitation, Figure 15 provides an inverse graph of the precipitation during 1974 by dividing the average monthly (annual/12) by the actual monthly precipitation in 1974. Overlayed on this graph is a plot of the average monthly geometric mean for all the monitors in King County that operated for the full year. This countywide average is utilized to discount major influences that certain activities may have on individual sites.

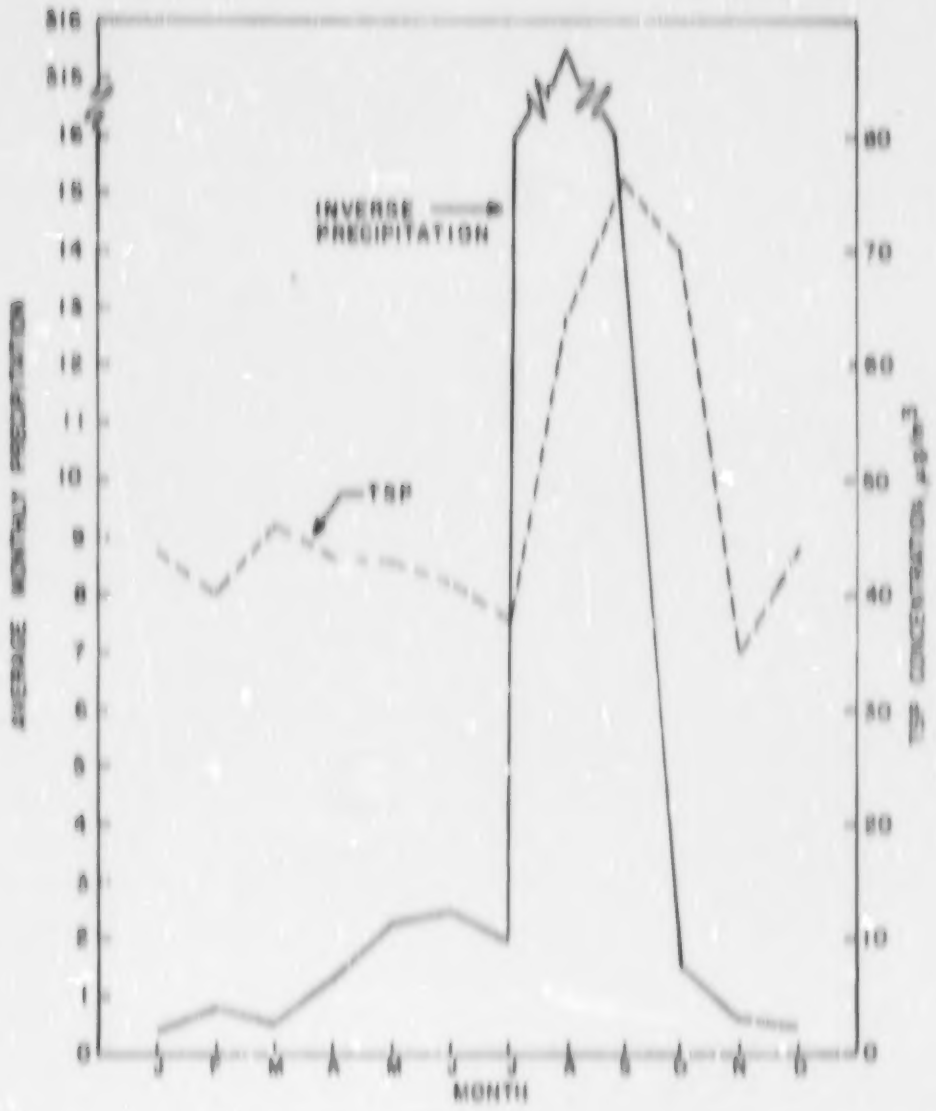


Figure 15. Monthly inverse precipitation - 1974, Seattle

The degree to which the inverse precipitation graph and the TSP concentration rise and fall together provides an indication of the correlation of the two parameters. The most pronounced characteristic of the precipitation plot is closely paralleled by the seasonal pattern in TSP.

This correlation must be considered even more significant since all other meteorological parameters (except for average monthly windspeed) would tend to indicate a pattern with higher TSP levels in the winter than in the summer. The fact that the pattern is not as closely paralleled during the rainier season may be partially explained by other meteorological factors such as ventilation characteristics. In addition, the daily pattern of precipitation may be used to better understand the impact that rainfall has on TSP levels. While Figure 15 would indicate that the rainfall in October was a sufficient amount to have a lower average TSP concentration for that month, almost all of the precipitation in October 1974 occurred within the last 6 days of the month and the other significant rainfall that month came in a downpour lasting about 5 hours on 1 day.

Just as precipitation has an impact on the short-term seasonal pattern of TSP concentrations, it can also affect the longer-term annual trends if the total level of precipitation varies significantly from year to year. In recent years in Seattle, the precipitation has fluctuated more than 20 percent on either side of the normal amount. This has led to differences of as much as 50 percent between 2 consecutive years. Again to provide an easier comparison of the correlation between the two parameters, a graph of the inverse (normal/yearly) precipitation and TSP levels measured at the NASN station on the Public Safety Building in Seattle between 1957 and 1974 is plotted in Figure 16. While there are obvious discrepancies in the correlation, this figure indicates that the precipitation has been having a measurable impact on the TSP concentration on a yearly basis. Of particular interest is the correlation in the most recent years which may be one explanation for the rise in TSP levels at a time when more sources were coming into compliance with the PSAPCA regulations.

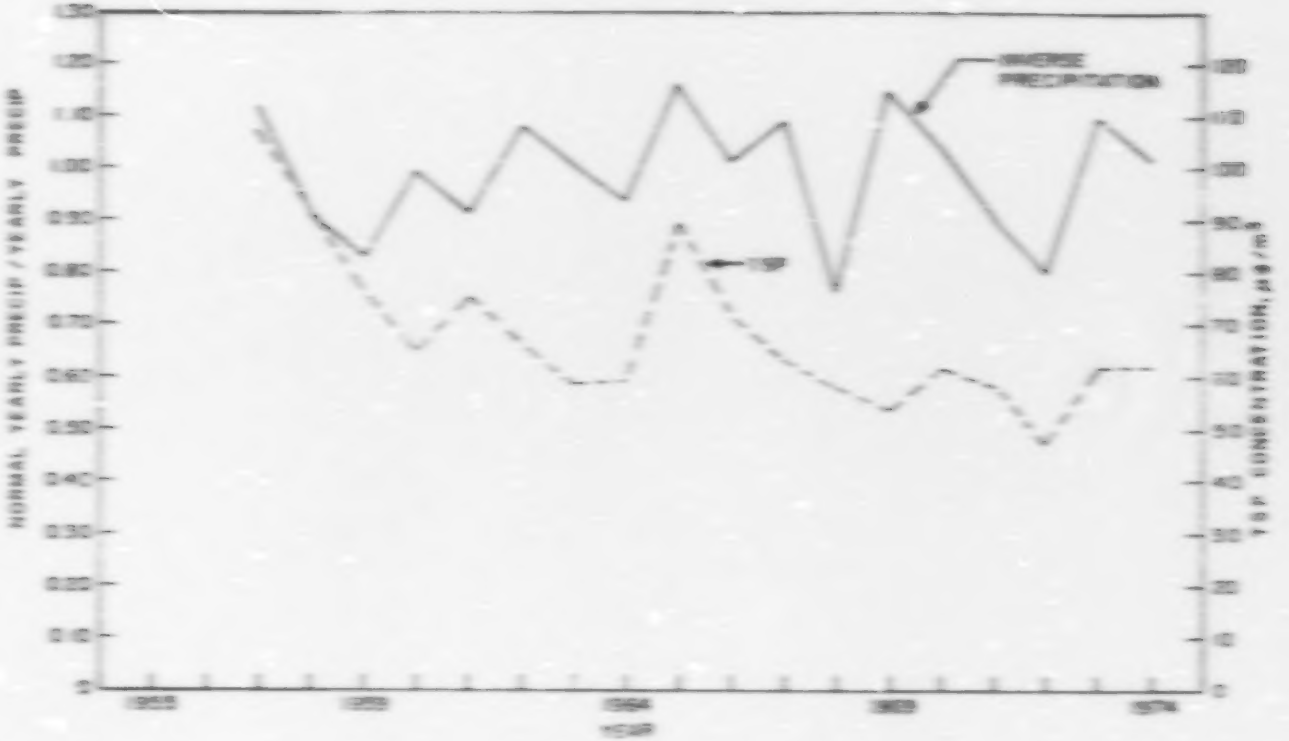


Figure 16. Normal/yearly precipitation and TSP concentration in Seattle, 1957 to 1974

URBAN ACTIVITY

Beyond industrial activity, fuel combustion, and other traditional pollution sources, it is increasingly apparent that in many locations other urban activities, such as routine traffic and construction and demolition activities, are a more major part of urban pollution problems than had been previously recognized. The primary area of interest in Seattle, because of published reports on the subject, was the problem of fugitive dust in the Duwamish Valley. It had been expected that data would be available on changes in concentration due to paving and road stabilization measures. However, this activity had not been completed and was too recent to have established any trends in TSP levels.

The other source of data that was identified for analysis of urban activity was the comparative study of the impact of the proximity of monitors to a heavily traveled street being conducted by the DOE. One of the hi-vols was located on top of an instrument shelter (height = 15 feet) immediately adjacent to E. Marginal Way, while the second hi-vol was located at the same height on top of a flat-roofed, one-story building set back approximately 100 meters from the street. The closer instrument shelter has a hedge-row of trees between the street and the monitor that provides some screening of street-generated particulates. Apart from this row of trees, there are no significant obstructions or local sources between the street and the second hi-vol.

Forty sets of paired measurements taken over the period from October 1974 to June 1975 are available for analysis. On 37 of the observation days, concentrations adjacent to the street exceeded those measured 100 meters from the street, with geometric mean concentrations at the two locations being 89 and 55 $\mu g/m^3$ respectively. These paired observations are plotted in Figure 17 to demonstrate the degree to which the monitor closest to the street is measuring higher levels.

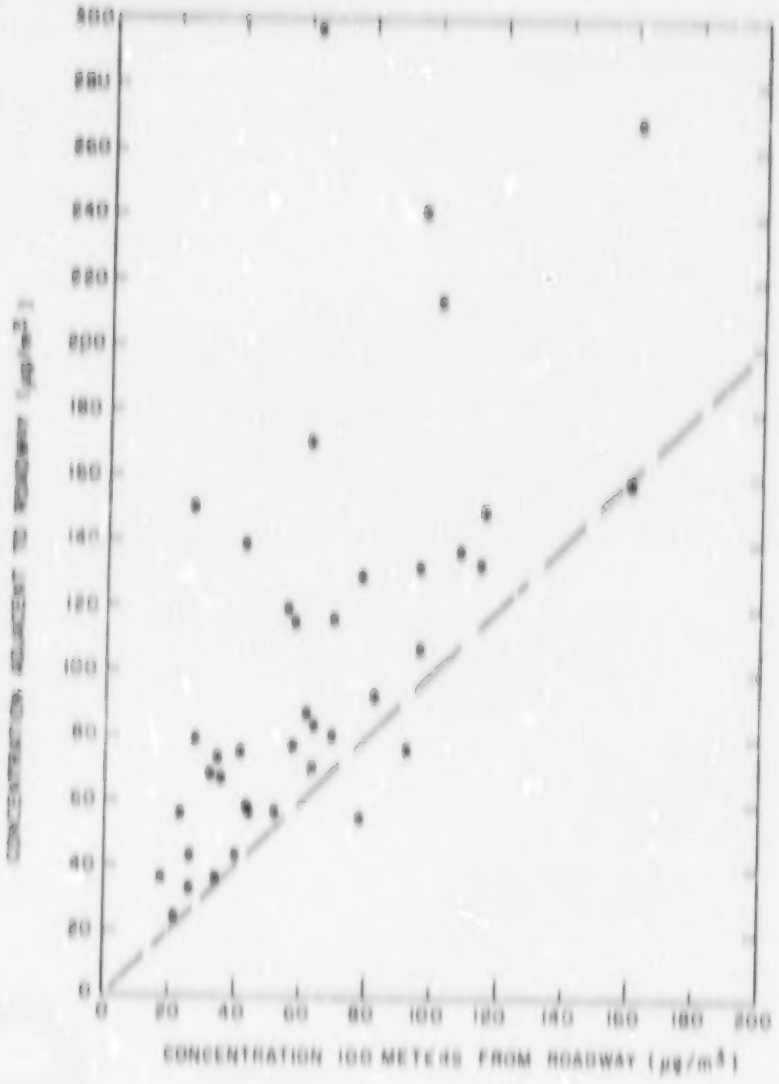


Figure 17. Comparison of TSP levels at two sites near E. Marginal Way, Seattle

While this data alone tends to indicate that the road is acting as a significant source, other analyses, including correlation with precipitation, wind speed, and wind direction, failed to indicate any of the effects expected if the road were actually a source. The lack of such effects is not conclusive evidence that the road is not the major cause of the increased values noted but rather that further data and consideration is needed. This is being pursued for the final report for this project.

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1. Cowherd, C. C., et al. Emissions Inventory of Agricultural Tilling, Unpaved Roads and Airstrips, and Construction Sites. Prepared for the U.S. Environmental Protection Agency, Office of Air and Waste Management, Office of Air Quality Planning and Standards, November, 1974.

2. Roberts, John W. The Measurement, Cost and Control of Air Pollution from Unpaved Roads and Parking Lots in Seattle's Duwamish Valley. A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering, University of Washington, 1973.

3. Air Quality Profile for King County Primary Abatement Area. Air Surveillance Section, EPA, Region X, Seattle, Washington. April, 1975.

4. Martin, W. and A. E. Steyn. The World's Air Quality Management Standards. Volume III The Air Quality Management Standards of the United States. U.S. EPA, October 1974. EPA-650/9-73-001-b.

5. A Plan for the Implementation, Maintenance and Enforcement of National Ambient Air Quality Standards in the State of Washington, prepared for the Environmental Protection Agency by the Washington State Department of Ecology. January 1972.

SECTION III

CONCLUSIONS

Both the primary and secondary standards for total suspended particulate are exceeded in the Duwamish-Harbor Island area of Seattle, and did not meet the 1975 attainment date as required by the state Implementation Plan. The portion exceeding the primary standards extends from the south end of Boeing Field to the northern portion of Harbor Island. The area exceeding the secondary standards extends farther south than Boeing Field, and on the north includes the Seattle Central Business District. This is a relatively localized problem in terms of King County as a whole, resulting from the high density of large sources in an adverse topographical setting.

According to the analyses in the EPA King County study[1] which assumed a 23 $\mu g/m^3$ influence from particulate from outside the area, the following estimated emission reductions would be necessary for standard attainment in the vicinity of the following stations.

	Primary	Secondary
Duwamish	15 percent	35 percent
Harbor Island	5 percent	13 percent
Municipal Building	-	8 percent

Also according to this study, the Compliance Data System (CDS) projects that by 1977 these necessary reductions will not be achieved. By that date, an additional point source emission reduction of only 2% percent is anticipated in the Duwamish area. The analysis of the regulations

given in Section II of this report tends to indicate that there is still potential for reducing emissions through more stringent regulations, especially process weight rate, without becoming unreasonable. Tightening of the process weight regulation to the statewide average stringency would result in as much as 50 percent less emissions from major sources.

Meteorology has been a complicating element in any planning for attainment strategies. The season pattern in precipitation is such that the controls are primarily needed to keep down the elevated levels in the dry summer-fall season as opposed to the winter when additional emissions from space heating would be expected to raise the TSP levels. Because of this seasonal variation, the most appropriate, cost-effective strategies may not be those relating to traditional control of industrial point sources. Rather, it may be more reasonable to put emphasis on the control of fugitive dust emissions during the several months of the year that the problem is prominent. Further study in this area is obviously warranted.

Precipitation may also have been a confusing factor in the review of progress to date. Between 1969 and 1972, precipitation would have impacted on the TSP levels to the extent that a downward trend was established. Since 1972, however, the precipitation has decreased and TSP levels have risen -- an unexpected occurrence given decreasing emissions. (The TSP trend plot given in this report is considered more pertinent than the one in the PSAPCA Air Quality Data Summary because a consistent set of monitors was used for establishing an average.)

With respect to these problems in the study of the area, the PSAPCA appears to have recognized them and is currently attempting to determine the relative contributions of fugitive dust and industrial emissions to the high particulate levels observed along the Duwamish Valley. The agency has devoted more than the normal amount of effort and resources in the monitoring and modeling of the area. In addition, the enforcement division has an active, well-structured program. As in most areas of the

county, further work is needed in tracking emissions from different facilities on a year-by-year and even a seasonal basis. The work underway at the PSAPCA directed at the computerization of the emission inventory for cross-referencing between years should be most helpful in this regard. The apparent lack of data on the spatial distribution of area sources needs to be resolved. Studies undertaken by Roberts, Boeing, and others have helped to provide much of the understanding of the problem area.

REFERENCES

1. Air Quality Profile for King County Primary Abatement Area. Air Surveillance Section, EPA, Region X, Seattle, Washington. April, 1975.

APPENDIX A

METEOROLOGICAL DATA

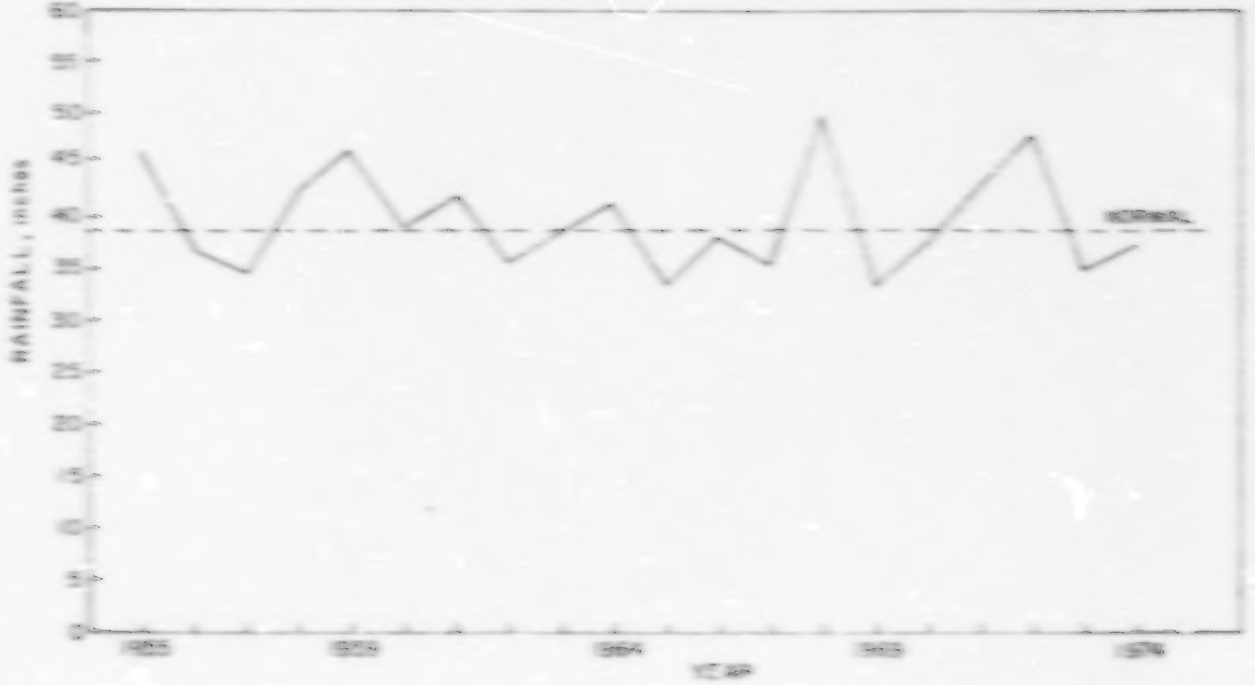

Figure A-1. Yearly rainfall in Seattle

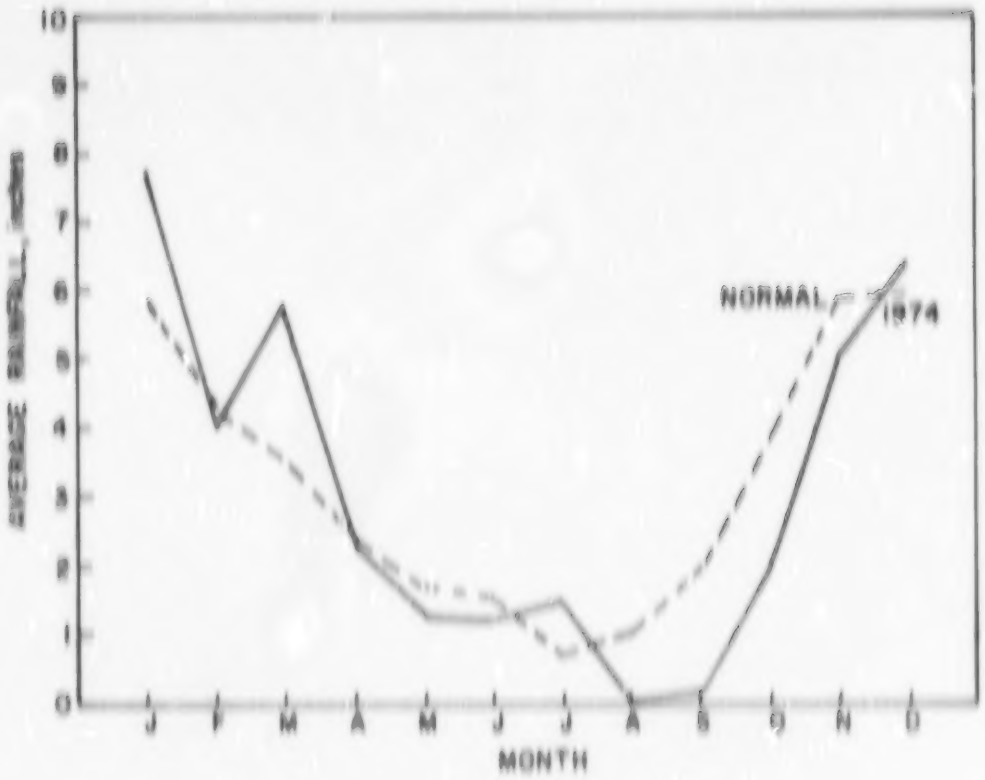

Figure A-2. Monthly rainfall in Seattle

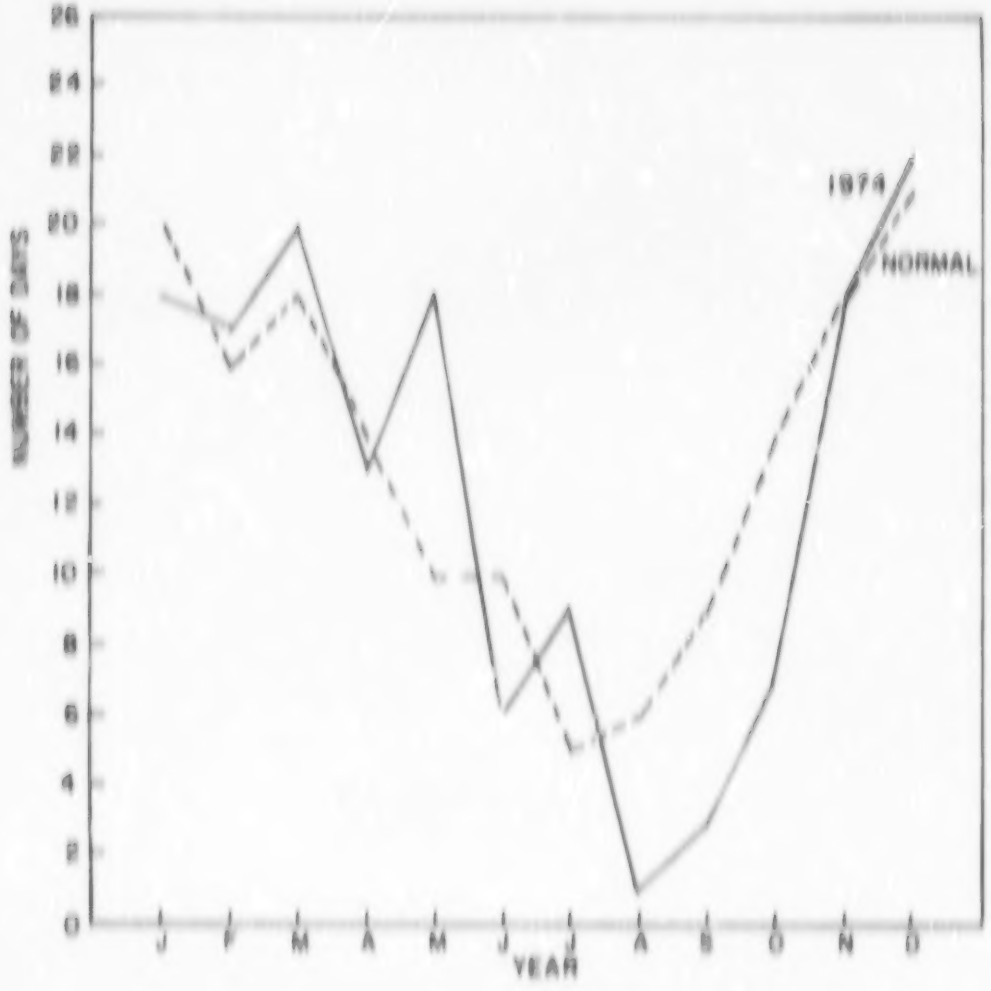

Figure A-3. Monthly number of days of rain in Seattle

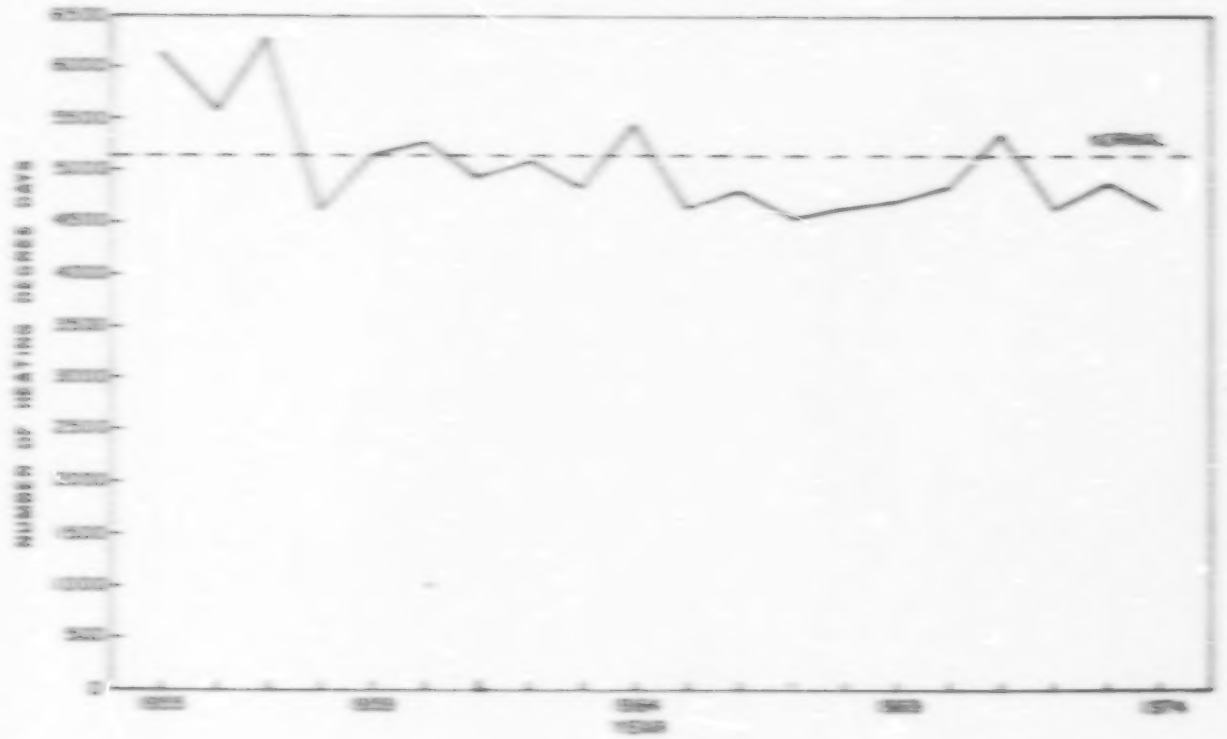

Figure A-4. Yearly heating degree days in Seattle

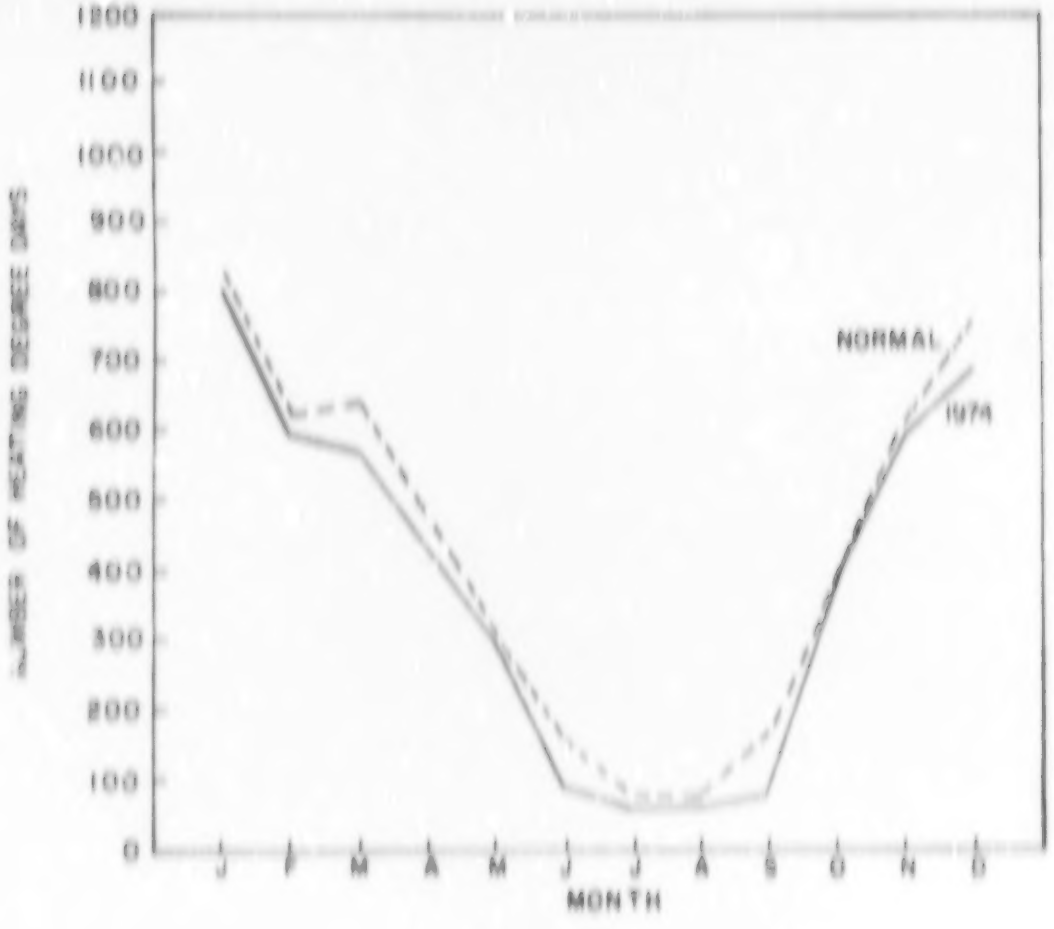

Figure A-3. Monthly heating degree days in Seattle

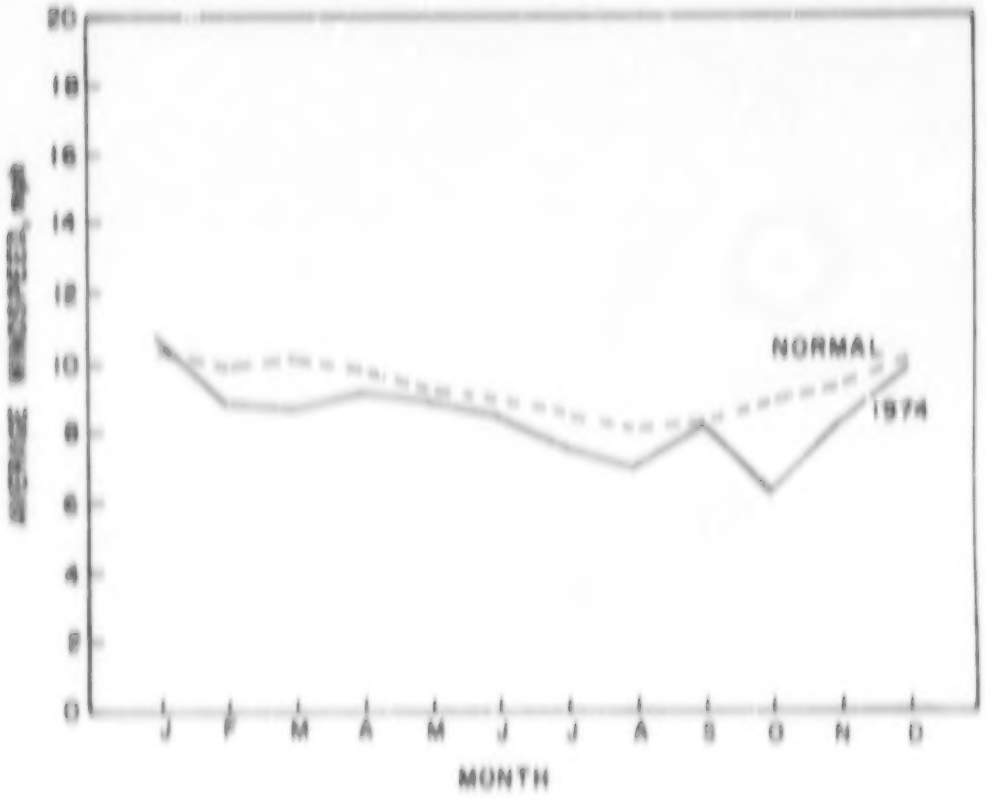

Figure A-6. Monthly wind speed in Seattle

APPENDIX B

PARTICLE CHARACTERIZATION

For most of the study cities members of the GCA study team acquired hi-vol filters from the 1976 filter banks of the cognizant local agencies. In addition, several filter samples for 1976 and selected earlier years were obtained from state and federal filter banks. Although some filters underwent chemical and/or detailed physical analysis, the principal purpose of obtaining filters was to utilize optical microscopy to identify each of the constituents that comprised more than five percent of the particulate mass. The selected filters, which were representative of several different site types and TSP levels within each study area, were returned to a clean room at GCA/Technology Division and carefully inspected for artifacts and evidence of sampler or filter malfunctions.

Each filter was then assigned a randomly generated five digit number which served as the only identifier for the filter sample so that each analyst had no information concerning the city, site, TSP loading or probable local sources associated with the sample. Furthermore, the use of two laboratories for the microscopy, coupled with the randomly generated identifying numbers, permitted a fairly comprehensive quality control program in the form of blind replicate analyses. Since both laboratories utilized more than one analyst, these procedures resulted in as many as four microscopists observing samples from the same filter and, in some cases, the same analyst examining replicate samples from the same filter as many as three times.

The results of this quality control effort, which are presented in Volumes I and II, warn against relying very heavily on the results of any one filter analysis. However, the random match-up between analyst and filter sample should minimize systematic bias in computed results.

Twenty-three filters from six sites were selected for analysis in Seattle and the meteorological data from the Seattle-Tacoma Airport for the selected sampling days are summarized in Table B-1. To gain some insight into the contribution of secondary particulates, much of which is too small to be observed by the microscopists, the annual average sulfate and nitrate concentrations for the NASN site are shown in Table B-2. The results for each of the filters submitted for routine analysis are presented in Table B-3. The results for the filters at each site have been averaged to give a composite of the particulate composition as shown in Table B-4. Six filters underwent replicate analyses, and the results are presented in Table B-5.

The composite particulate characterization for all filters from Seattle that underwent routine analysis, presented in Table B-6, shows that minerals predominat but not to as great a degree as observed in many study cities. Only three cities had lower average percent minerals than Seattle. Quartz was the major mineral constituent observed (over half of the mineral content) followed by lesser but nearly equal amounts of feldspars and calcite. The DOE site, which recorded the highest TSP levels in 1974, showed somewhat larger than average amounts of minerals presumably because of its proximity to the highway.

The site with the lowest average percent minerals was the Public Safety Building (E-1) which seems to be consistent with the high sampler location (80 feet above ground). Oddly, this site also recorded the highest levels of rubber, an observation apparently inconsistent with the sampler location.

Table [illegible] METEOROLOGICAL DATA ON SELECTED SAMPLING DAYS (SEATTLE-TACOMA AIRPORT)

Date	Precipitation, in.		Wind speed, mph		Wind direction, deg	
	No. of obs.	Freezing obs.	Average	Resultant	Individual obs.	Resultant
6/10/75	0	0	8.3	8.0	20, 10, 170, 70, 180, 210, 110, 30	100
6/28/75	0	0	7.3	7.2	10, 10, 200, 330, 310, 350, 0, 110	340
7/23/75	0	0	8.3	8.3	20, 10, 10, 170, 180, 170, 210, 360	350
8/15/75	0	0	5.3	5.1	0, 0, 300, 280, 270, 290, 0, 10	290
9/26/75	0	0	7.3	7.3	10, 110, 120, 140, 180, 170, 160, 100	130
10/08/75	0	0	5.8	5.8	20, 10, 130, 10, 190, 200, 10, 0	100

N/A = [illegible]
[illegible]

Table [illegible] ANNUAL AVERAGE CONCENTRATION OF SULFATE AND NITRATE IONS AT THE SEATTLE, WASHINGTON (DOWN WIND NO. 1 STATION) ($\mu g/m^3$)

Year	Sulfate		Nitrate	
	Arithmetic mean	Geometric mean	Arithmetic mean	Geometric mean
1972	6.17	6.01	1.56	1.32
1973	5.64	5.51	2.38	2.09
1976	5.59[a]	5.19[a]	2.15[a]	1.95[a]

[a]Indicates insufficient data for statistically valid year.

Table B-3b. RESULTS OF FIELD ANALYSES FOR SELECTED SITES IN SEATTLE AND VICINITY
(Seattle Island - Oct. 6-Nov.)

Site																				

Table B-4. COMPOSITE SUMMARY OF FILTER ANALYSES FOR SELECTED SITES IN SEATTLE AND VICINITY

TABLE B-1. RESULTS OF REPLICATE ANALYSES OF SEATTLE FILTERS

Table B-6. CITYWIDE COMPOSITE SUMMARY OF FILTER ANALYSES IN SEATTLE

No. of filters	33	
	Quantity, percent	
Components	Average	Range
Minerals	(60)	30-96
Quartz	35	7-65
Calcite	9	1-20
Feldspars	10	0-28
Hematite	5	1-15
Mica	<1	
Other	1	0-4
Combustion Products	(27)	1-62
Soot:		
Oil	10	0-25
Coal	6	0-22
Misc. soot	1	0-10
Glassy fly ash	<1	
Incinerator fly ash	9	0-45
Burned wood	<1	
Burned paper	<1	
Magnetite	1	0-6
Carbon black		
Other		
Biological Material	(3)	tr-24
Pollen	1	0-20
Spores	<1	0-2
Paper	1	0-3
Starch	<1	0-2
Misc. plant tissue	<1	0-2
Leaf trichomes	1	0-18
Miscellaneous	(10)	<1-60
Iron or steel	<1	0-2
Rubbery	10	0-60
Other	<1	0-15